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ABSTRACT

Navy personnel research conducted a comprehensive review of the literature on computer simulation studies to determine whether simulation methodology could be used to improve scientific understanding of psychosocial and sociotechnical systems. The literature search indicated that computer simulation could provide tools for the study of organizational behavior, and it was concluded that the advantages resulting from using simulation techniques outweigh the difficulties encountered in their implementation. (CH)

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COMPUTER SIMULATION: A TECHNIQUE FOR STUDYING PSYCHOSOCIAL AND SOCIOTECHNICAL SYSTEMS

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ABSTRACT

A comprehensive literature review indicated that computer simulation methodology can be used to overcome obstacles impeding man's understanding of, and scientific advancement in, psychosocial and sociotechnical systems. Many investigations were identified which demonstrated the feasibility of using simulation techniques to analyze and synthesize organizational systems. It is considered that the accrued advantages and potential payoffs resulting from using simulation techniques far outweigh any pitfalls that may be encountered in their implementation.

FOREWORD

In preparation for Advanced Development work in organization design and manpower utilization (Manpower Management Effectiveness Subproject, ZPN01.04: Improved Manpower Utilization) various research and development technologies were evaluated. Computer simulation of social/organizational systems was given substantial consideration in the course of which the relevant literature was surveyed, summarized, and reported in this publication which we hope will be of interest to others researching this area.

The assistance of Kim Brun and Doug McCalla in retrieving the many articles, reports, and texts for the extensive literature review, and of Victoria Tate in typing the lengthy manuscript, is appreciated and acknowledged.

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A portion of this research was presented at the meeting of the American Psychological Association, Chicago, August, 1975.

J. J. CLARKIN
Commanding Officer

SUMMARY

Problem

Many difficulties impede the scientific understanding of, and the application of knowledge to, psychosocial and sociotechnical systems. In the area of organizational behavior, some of these obstacles concern: complex social systems, psychosocial variables, formulation and verification of theory, experimental techniques, and organizational structure and change.

Purpose

The objectives of this research effort were:

1. To determine whether computer simulation methodology can be used to overcome these obstacles.

2. To examine computer simulation studies in which psychosocial variables were incorporated or manipulated in the computer models.

3. To identify any pitfalls that may result from using computer simulation methodology.

Approach

A comprehensive review of the relevant literature was conducted. Studies incorporating psychosocial variables in the computer models were classified according to scope and nature.

Results

The literature search indicated that computer simulation methodology could be used in surmounting these impediments, and providing various advantages for the study of organizational behavior. Also, many investigations were identified which demonstrated the feasibility of using simulation techniques to analyze and synthesize psychosocial and sociotechnical systems.

Conclusions

It is considered that the accrued advantages and potential payoffs resulting from using simulation techniques to investigate organizational systems outweigh the asserted snares or pronounced pitfalls encountered in their implementation.

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APPROACH

A comprehensive review of the relevant literature was conducted. Results are shown in the following section, broken down under appropriate headings.

FINDINGS AND DISCUSSION

Impediments Which Computer Simulation Methodology Surmounts

Organizational Theory

In 1965 Cohen and Cyert implied that the further development of organizational theory is hindered by two widely followed methodological impediments. The first of these is the usual procedure of studying individually and independently the separate segments of an organizational system. This is done most of the time without paying adequate attention to the multifaceted interrelationships that exist among organizational variables which by nature are inextricably intermingled. The second obstacle seems to compound the first, by typically employing experimental procedures, which are only suited to the simultaneous investigation of the alleged effects of only a very small number of variables. These inappropriate and ineffective techniques are utilized in a moronic manner, inspite of the very high probability that a whole gamut of multitudinous variables, may be jointly responsible for the observed organizational

behavior. Scott (1964) reinforced some of Cohen and Cyert's concepts by asserting that no widely accepted theory of organizations exists--only a number of speculative schemes or structures focused upon the differential aspects of organizational behavior. These organizational concepts are usually complemented by a rapidly growing aggregation of empirical generalizations, and by a relatively small number of well done descriptive studies of concrete organizations. In order to have a more thorough integrated knowledge of organizational phenomena, it is desireable to demonstrate that our understanding of the individual components and aspects can be synthetized into a total organizational systems theory.

According to Cohen and Cyert, since the ultimate goal of organizational theory is to explain and predict with confidence the behavior of organizational systems, and not their segmented or individual components, it is absolutely necessary to have an improved methodology which will give organizational researchers, theorists, and managers the capability to design, manipulate, and evaluate total organizational systems. Similarly, Koenig (1965) stated that one of the primary problems impeding process in the empirical investigation of organizational systems is a suitable, significant, and quantitative procedure. Apparently, one of the main deficiencies in much of the organizational research to date, has been the inability to extrapolate from a knowledge base of micro-components (e.g., structure and dynamics of small groups, decision-making processes, formation and changing of attitudes, or manipulating contingencies and incentives) to the development of a knowledge base of macro-components (e.g., optimizing organizational effectiveness and efficiency, improving manpower utilization, implementing organizational development programs, or enhancing the diffusion of novel ideas or technology). This lack in the organizational area underscores the importance of, and requirement for, using computer simulation methodology.

Cohen and Cyert were convinced that in the future a large portion of the fundamental research focusing on the behavior of complete organizational systems will be performed utilizing computer simulation techniques. In a supporting fashion, McLeod (1974) mentioned that one of the greatest difficulties in determining the probable impacts of different action alternatives on social systems, is that prolonged time lags are inherent in such sluggish systems. Consequently, he advised against directly experimenting on these systems, for reactive and irreversible forces might produce undesirable results, or at least intermediate confounding effects, prior to the assessment of long-term impacts. Since computer simulations are time independent, they easily and essentially surmount this irksome impediment. By studying organizational systems from multidisciplinary views, diverse academic skills can be utilized to analyze and solve the same problem. Bauer and Buzzell (1964) proposed the integration of various analytical concepts and techniques in order to produce more effective and useful results, rather than the separate or individual utilization of these procedures or methods. Therefore, they suggested combining concepts from the behavioral sciences with the techniques of computer simulation to define, examine, and solve sociotechnical system problems.

Complex Social Systems

According to Pool (1964), "The nemesis of applied social science up to now has been the hideous complexity of the systems of variables--non-linear and discontinuous ones at that--with which they deal." Pool pronounced that computer simulation methodology was a massive break-through for the behavioral sciences, since it provides a procedure for simultaneously or sequentially examining and manipulating a complete constellation of variables and parameters (social and technical, continuous and discontinuous), all of which are indubitably intertwined. Likewise, Colby (1963) claimed:

> "Before the computer program we had no satisfactory approach to huge, complex, ill-defined systems difficult to grapple with, not only because of their multivariate size but also because of a property of elusiveness which in psychology is mainly a function of vagueness in that the limits of inclusiveness of conventional terms are unclear."

Borko (1965) mentioned that the computer enables the social scientist to study complex problems which previously were considered impossible and insoluable. By simulating social systems on a computer, researchers can make inferences by analogy about complex human behaviors, and then evaluate and validate these suppositions.

Dutton and Briggs (1971) seemed especially enthusiastic about the role that computer simulation can play as a means for deciphering complicated social processes. In these circumstances, simulation serves two essential functions: (1) it coalesces a diversity of otherwise disparate elements into a single entity which is capable of being studied in itself, and (2) it reduces an intricate phenomenon into manageable components which are more easily understood in themselves. As affirmed by Loehlin (1965), what a less complicated model loses in fidelity may at least be partially offset by a gain in manageability. Similarly, Crane (1962) suggested that computer simulation will enable social scientists of the future to represent more accurately the intricate interrelationships among variables affecting human behavior. It would do this by making it feasible to manipulate systematically and successfully many more variables and relations, than an investigator could hope to handle within a reasonable time frame. Even though simulation techniques make complicated problems much more tractable, Clarkson and Simon (1960) claimed that this does not in any way excuse the social scientist from carefully selecting variables for study, especially since the real world is so much more complex than the multivariate models which can be simulated on even the most modern computers. Consequently, social scientists must seriously consider what intelligible aspects of realistic phenomena must be abstracted and incorporated within computer simulation models, if these techniques are to provide probable, reasonable, and useable solutions to immediate and important problems. Coe (1964) claimed that not only does computer simulation permit the definition and examination

of multidimensional interrelationships with the effects of known confounding variables controlled or removed, but also it permits precision and accuracy through simulated measurements seldom found in field research. Furthermore, simulation procedures can produce probable results in only a small fraction of the time needed for more conforming or conventional field research procedures.

Dawson (1962) declared that computer simulation is a very useful methodology, when the reseacher has an adequate knowledge base about the real social system to capture and reproduce its behavior with sufficient fidelity in an operating model. However, regarding the simulation of poorly understood social systems, Simon (1969) stated that simulation techniques can assist the researcher, even when he initially does not know very much about the interrelationships among the variables comprising the complicated system. He mentioned that investigators are seldom attempting to explain or predict phenomena in all their particularities, but seem much more inclined or interested in the understanding of only a few aspects abstracted from complex reality. Apparently, the more researchers are willing to abstract from a complex, real-world system, the more easy it is to simulate and comprehend. Fleisher (1965) reinforced to some extent some of Simon's notions, by affirming that many simulations devised in the social sciences, are for problematic systems where no sufficient mathematical knowledge exists, "only conjecture--vague, tentative, and intuitive." Under these conditions, simulation is utilized to deduce the implications of an unrefined systemic structure constructed from simple suppositions.

Psychosocial Variables

Pool (1964) proclaimed that, when planning or designing a number of complicated and costly systems, what is normally neglected is the human factor or dimension. In order to accurately anticipate the consequences of any sociotechnical system, human behavioral or performance variables (e.g., information processing, learning abilities, motor-skill performance, physiological limitations, perceptual capabilities, extrinsic or intrinsic incentives, ingrained attitudes, decision-making strategies, communication networks, or many other salient factors), must necessarily and sufficiently be taken in consideration. These "human intangibles" should be taken into account, now more than ever, since sociological and psychological research in recent years, has significantly increased the breadth and depth of our knowledge base regarding human behavior. In addition to the physical, technical, or "hard" variables which are typically attended to in the design and development of advanced systems; psychological, sociological, or "soft" variables ought to be given their due consideration when analyzing total system performance. It is shear "idiocy" not to take into account these intangibles or soft variables, together with tangibles or hard variables, because they obviously and mutually impact upon each other.

One means of simultaneously considering a whole gamut of variables, psychosocial and technical, which indubitably interact in real-world systems, is to employ computer simulation methodology. This technique is a means of merging or coupling the precise calculations of the operations researcher, with the scientific and intuitive insights of the behavioral investigator. Rosenhead (1968) affirmed that in the past operations research has had only some success in managing problems which involve psychosocial processes. However, these dynamic situations can be simulated by using simplified assumptions concerning psychological or sociological phenomena. In other words, computer simulation should be considered as an experimental technique, and not a means of exactly explaining or describing sociological or psychological behavior. By blatantly disregarding "soft" variables, many so called solutions of operations research have been undeniably weakened, by the powerful impact of psychosocial factors upon total system performance. In fact, many critical and vital problems are totally neglected by operations research because these intangible variables obviously and clearly cannot be totally ignored.

Dutton and Briggs (1971) defined simulation as "a duplication of the essence of a system or activity, i.e., the essential characteristics of the system...realism is not necessary." According to them, the computer must necessarily and accurately capture, represent, express, or depict the intrinsic structure or relations among the components constituting the system being simulated. Rowe (1965) stated that "computer simulation can be considered as an attempt to model the behavior of a system in order to study its reaction to specific changes." Both he and Rosenhead (1968) thought that computer simulation involved the use of simple analogues of systemic structures or processes, rather than high fidelity facsimiles. Congruently, Rivett (1967) affirmed that simulation was "an attempt to transform a real life situation into one in which experimentation by allegory [or symbolic description] is possible in order to guide the decision maker to a conclusion." Zelditch and Evan (1962) stated that computer simulation "...manipulates, simplifies, transforms, substitutes other properties of the natural world such that it is artificial." Possibly, this is one reason why some people have such ingrained negative attitudes towards simulation per se. As Simon (1969) mentioned, "...the term 'artificial' has a pejorative air about it...". He thought that it conveyed a sense of the "...affected, factitious, manufactured, pretended, sham, simulated, spurious, trumped up, unnatural... [as opposed to the]...actual, genuine, honest, natural, real, truthful, unaffected."

Verification of Theory

Crane (1962) claimed that computer simulation programs could be considered as a novel language or idiom in which theories could be expressed or symbolized. Gullahorn and Gullahorn (1965a) mentioned that computer simulation significantly contributes to the creation and verification of social theory. By stating precisely as a computer model the principles or assumptions intrinsic to a theory, a relatively tractable representation or symbolic system can readily be conceptualized. This is so since the process of programming a computer model by nature necessitates linguistic precision or clarification of concepts. Gullahorn and Gullahorn seemed to support

some of Crane's notions, in that they thought computer simulation programs were essentially dynamic. Such simulations can set in motion speculative or systemic processes, and thus generate reams of data which flow logically and indubitably from these theoretical dynamics. Alker (1970) asserted that computer simulation programs are themselves understandable or interpretable as theory. He also implied that the creation and elaboration of theory itself has been affected enormously by "...the metaphor of computer-like information-processing systems...[and the] conventions of computer programming."

Frijda (1967) affirmed that the primary purpose of computer simulation methodology is to reveal readily and lucidly theoretical consequences. Likewise, the Gullahorn's (1965a) mentioned that a computer model could actually set speculative processes in motion, thereby realizing both short- and long-term implications. The data generated during a simulation cycle are directly and exclusively the products of simply operationalizing theoretical structures, and are not, in any way, confounded by extraneous, unprogrammed parameters or variables. Brightman and Kaczka (1973) asserted that by constructing and exercising computer simulation models, theoretical discontinuties or incongruities are likely to be uncovered conspicuously. Consequently, scientists could direct the necessary attention and effort toward filling these hypothetical voids in their knowledge. Simon (1969) stated that even when researchers have the correct premises, it might be very tedious and difficult to discover their theoretical implications. Computer simulation techniques could clearly deduce the speculative consequences of a multitude of intermingled variables, starting from a very complicated set of initial conditions. In a similar manner, Alker (1970) affirmed that theoretical extrapolations necessarily flow from computer simulation models and their input data, since they are tautologically contained within the premises of these programs. Therefore, he declared that "...simulation models have all the advantages of rigorous content-free deductions...."

Clarkson and Simon (1960) stated that computer simulation is a methodology for constructing theories which reproduces or mimics the actual behavioral output of a dynamic system. Pool and Bernstein (1963) thought of simulation techniques as procedures for playing out the past into the future with mathematical rigor and electric speed, in order to determine to the extent feasible the significance of scientific assumptions. Borko (1965) considered behavioral theory and computer simulation programs to be identical. Consequently, he claimed that simulation methodology primarily compels the scientific speculator to be precise and complete in his formulations, and secondarily, provides easy and exact tests of theoretical assumptions by comparing the behavior of simulated processes with actual activities. In a similar fashion, Clarkson and Simon (1960) asserted that one of the main attractions of computer simulation methodology is the opportunity and ability it affords for the "...direct confrontation of theory with concrete behavior." Reitman (1963) mentioned that computer simulation models could make many valuable contributions to the development of theory. He enumerated three salient reasons for this effect: "...[1] since they provide a unique opportunity for concept objectification..., [2] since they allow us to separate tests of

the implications of a theory from the associated measurement problem..., and [3] since they permit us to work in terms of processes and structures as well as attributes...." Sisson (1969) stated that computer simulation techniques will facilitate the consolidation of what little scientists know about some theoretical processes. Consequently, these procedures will greatly assist in the more distinct definition of what data are discriminating.

Formulation of Theory

Loehlin (1968) stated, in a surprising fashion, that the prime impact of computer models upon psychological theory, is not in the least due to the actual running or exercising of these simulations. But their importance should be attributed to these computer programs as an inexhaustible source of concepts, symbols, and linguistics--novel ways of expressing theoretical propositions. Several other scientists seemed to agree with Loehlin's assertion. Gullahorn and Gullahorn (1965a) mentioned that the very act of programming or coding in computer language impels the scientist to be very precise about variables and their functional relationships. This process, in turn, facilitates the lucid statement of conceptual schemes, by enabling the researcher to recognize readily ambiguities in the expression of scientific structures and processes. Consequently, the Gullahorn's considered computer simulation methodology as a unique and indispensable instrument, for creating and developing intellectually powerful and mathematically precise theories. Dill (1963) declared that computer programming languages provide researchers with a salient alternative to typical English and mathematics for stating behavioral theory. He claimed that: "Computer program theories are more precise, and thus easier to test and evaluate, than most verbal theories; they can describe many kinds of behaviors more flexibly than the highly formal techniques of mathematics and statistics." Crane (1962) mentioned that by using simulation techniques, the scientist is constrained to be more precise and accurate in defining and manipulating variables and functions regarding social systems. Similarly, Frijda (1967) affirmed that simulation models easily function as unambiguous formulations of psychosocial theories, due to the demanding exactitude of computer programming languages. Roby (1967) also concerned himself with the intrinsic utility of computer simulation as a theoretical tool to facilitate the definition and development of organizational concepts.

Guetzkow (1972) stated that simulation techniques could be utilized to integrate prevalent psychosocial theories, since "...[they] permit the coherent amalagation of sub-theories into interactive, holistic constructions of great complexity...." Likewise, Loehlin (1965) claimed that there is tremendous merit in depicting psychological processes by computer simulations. This is attributed to their facility to juxtapose and coalesce several subprograms with one another, which frequently produces many interesting and surprising emergent properties. Pool (1964) proclaimed that no spectacular behavioral theories really exist--only "well-documented regularities." Therefore, the future of the social sciences is contingent upon identifying techniques to link simultaneously a multitude of relatively trivial conceptual structures. Computer simulation methodology is precisely suitable for manipulating many propositions instantaneously, when

no premise alone is powerful enough to determine the state of the system at any moment. Beshers (1968) asserted that to state sufficiently and appropriately behavioral theory, it should be expressed or embedded in computer simualtion models, since typically these structures contain many parameters and variables. Sisson (1969) asked rhetorically, "Which comes first, the data or the model?". He answered by saying that most social scientists claim "the data". Sisson said that by replying in this manner, these researchers propagate the myth that models emerge out of massive efforts to collect data, independent of theoretical guidelines. He retorted by declaring that "[these scientists] do not understand the role that computer simulation models play in defining what data is useful, and in developing theory."

Experimental Techniques

Martin (1959) maintained that one of the essential reasons for the tremendous void in suitable scientific knowledge of psychosocial systems, has been consistently attributed to the absence of appropriate experimental paradigms, procedures, and facilities for examining, manipulating, and evaluating organizational structures and processes themselves. Typically when an investigator attempts to experiment empirically with these systems, his best efforts are totally thwarted by reactive techniques and measures, by the inextricable labyrinth of behavioral variables, and by an almost complete absence of suitable controls. Therefore, computer simulation methodology was an immeasurably important breakthrough in the furtherance of scientific understanding of psychosocial systems, since it easily enables researchers to overcome confidently the hindrances involved in the study of "real-world" organizations or groups. McWhinney (1964) thought that it will become exceedingly exorbitant in time and money to procure sufficient sample sizes, for the "live" investigations to study increasingly larger organizations and seemly richer environments. Similarly, Dutton and Briggs (1971) claimed that circumstances not only may preclude the use of conventional field or laboratory procedures, but also may preclude the use of empirical investigations with live subjects "on humanitarian, political, or financial grounds." Dill (1963) declared that researchers usually give organizational phenomena "short shrift" since they are rarely ever able or willing to conduct studies "with real people and real organizations." All of these scientists implied that the efforts exerted in computer simulation studies, should be exceedingly useful in overcoming the many impediments mentioned above regarding the experimentation with real psychosocial systems. Also, according to Kruger (1963), in addition to exercising complete control over both intrinsic and extrinsic variables, there are other advantages of using simulation to study behavioral problems. These benefits are due to (1) the facility with which computer models may be employed to relate many variables in an almost infinite number of possible combinations, and (2) the capability which simulation techniques permit researchers to utilize meaningfully reams of accumulated data that otherwise would likely remain disused.

Organizational Structure

Several researchers suggested that computer simulation techniques could be used for analyzing, devising, and evaluating organizational structures and processes. Dill (1963) declared that simulation methodology should be employed to design and test organizational systems. Martin (1959) mentioned that computer simulation will probably develop into an immeasurably potent technique for further comprehending the rudiments regulating organizational performance. Marshall (1967) stated that simulation procedures provide the potential for studying synthetically simplified organizational systems which in turn yield valuable insights into real structures and dynamics. Coleman (1964) claimed that not only are computer models extremely adapted to problems that pertain to organizational structures, but also are especially suited to questions that involve psychosocial processes. He asserted earlier in 1961 that since simulation techniques enable investigators to take into consideration structural connections, the object of scientific observation and evaluation need no longer be the behavior of organizational elements, but the complete system itself. Also, by combining structures and processes at the microsystem level, computer models could easily be used to extrapolate these phenomena to the macro-system level, thereby revealing the behavioral consequences for the total organization. Likewise, Martin indicated that simulation methodology could readily be employed to integrate overtime many submodels of organizational phenomena, and then to observe the numerous interactive effects among these artificial components.

Kuehn (1965) emphasized that by constructing and exercising computer simulation models, managers as well as researchers could readily plan and test operational alternatives. Dutton and Briggs (1971) thought that whenever it is infeasible to interrupt, manipulate, and study sufficiently an organizational operating system, simulation procedures could be utilized effectively under these circumstances, to investigate indirectly functional activities. In these situations, computer modelling contributes to the comprehension of which parameters and variables are most decisive in determining systemic behavior. Dill (1963) indicated that not only will computer simulation have an important impact upon approaches to organizational analysis, design, and evaluation; but also it will have an eminent effect upon procedures for managerial assessment, training, and development. By simulating organizational structures, processes, and environments, present or future managerial plans, programs, and policies can be easily evaluated. Dawson (1962) definitely agreed with these notions which were then very avant-garde. Gullahorn and Gullahorn (1964) affirmed that simulation techniques could be utilized to investigate the impact of managerial decision-making upon such organizational phenomena as worker motivation, individual satisfaction, task-group cohesion, and organizational climate. Pool and Bernstein (1963) implied that it is possible to study via computer simulation other organizational aspects--absenteeism, turnover, morale, productivity, efficiency, information-flow, incentives, attitudes, rewards, stress, and strain. Also, Crane (1962) claimed that simulation procedures could be employed to examine still more social system facts from ideational diffusion and mass communications to influence techniques and coalition formation.

Organizational Change

Dill (1963) declared that organizational changes are usually planned and prepared very causally and carelessly. Many notions regarding social structures and processes are typically defined or expressed in very shallow or simplified propositions which do not sufficiently reflect situational dynamics. McPherson (1965) mentioned that simulation methodology not only surmounts these problems, but also overcomes difficulties due to the obvious systemic nature of most organizational changes, and the inherent time lags involved in implementing novel procedures. Schultz (1974) also asserted that simulation techniques could be used to facilitate effectuating social system change or innovation. Dutton and Briggs (1971) claimed that computer modelling accomplishes this by permitting managers and researchers to implement, observe, and evaluate simulated organizational changes. Gullahorn and Gullahorn (1972) similarly stated that an attractive attribute of simulation methodology derives from its intrinsic capacity to program speculative change processes within psychosocial systems. Malcolm (1958) concerned himself with "installation theory--...[the] study of the overall most efficient way of introducing change." There is a tremendous requirement for more effectively and efficiently introducing and implementing change, since acquisition and execution times are such significant segments of a system's longevity and expense. Although, social system simulation may not be a panacea, it does readily offer a remarkable remedy for this organizational deficiency.

Dill (1963) declared that "[s]imulation techniques are for the organizational planner what the wind tunnel is for the aeronautical engineer." Thus, once the problem definition phase has been completed and action alternatives enumerated, then computer simulation could be employed to attain much more quickly, feedback regarding potential systemic structures and dynamics. Furthermore, this procedure would preclude premature commitments concerning future organizational configurations. McPherson (1965) mentioned that frequently innovative organizational processes or procedures are not successfully implemented because of lack of understanding of the consequences. Malcolm (1958) seemed to agree with this assertion, and maintained that a primary advantage of employing simulation methodology is the ease with which it enables one to comprehend the implications of potential organizational changes. Radnor, Rubenstein, and Tansik (1970) referred to a similiar situation by using the "change-squared concept." It implied that computer simulation plays the role of a change-agent, by allowing organizational members, managers, and researchers to more easily accept alterations in social system structure and dynamics. Schultz (1974) asserted that this process can be facilitated by having both the builders of computer models, and the managerial users of these simulations, jointly and actively idenfity and define organizational problems. Likewise, Malcolm (1958) implied that it was paramount to permit the affected party to participate in simulation activity, in order to ease organizational change via computer modelling. Also, Sprowls and Asimow (1960) insinuated that implementation of innovative social systems could be enhanced by possessing a library of computer models of various organizational components. By having them available, these modules can be concatenated to simulate relatively effortlessly many different configurations of tentative organizations.

Computer Simulation Studies of Psychosocial and Sociotechnical Systems

Background

Two reviews and three bibliographies have been conducted and reported regarding the computer simulation of human, social, or organizational behavior. In 1965 Cohen and Cyert considered many manners in which simulation techniques have been employed to investigate various characteristics of organizational behavior. They surveyed four distinct categories of organizational simulations, namely: (1) descriptive studies which delineated representive behavior in actual organizations, (2) illustrative investigations which examined the processes of "quasi-realistic" organizations, (3) normative models which assisted in improving the design of organizations, and (4) man-machine simulations which permitted the training of people in organizations. Roeckelein (1967) prepared an annotated bibliography on the simulation of organizations. His intention was to develop a rudimentary knowledge base, for evaluating the feasibility of using several simulation techniques (man-centered, man-machine, and machine-centered), in order to perform research regarding human parameters which impact upon organizational performance. Werner and Werner (1969) reported a bibliography of simulation studies which dealt with the description of human behavior, or with the construction of computer models for formulating facts on human behavior. They concerned themselves with those investigations which considered four characteristics of human behavior--perceiving, learning, decision-making, and interacting. Dutton and Starbuck (1971) compiled a very complete bibliography of the literature relevant to the computer simulation of human behavior. They organized the material into four categories, namely--"individuals, individuals who interact, individuals who aggregate, and simulation methodology." Dutton and Starbuck asserted that their tedious endeavor mirrors the rapid growth and development of computer simulation technology. It should be noted that the results of their tremendous effort also appears in Starbuck and Dutton (1971). Also, Gullahorn and Gullahorn (1972) reviewed and reported numerous and diverse simulations of socio-cultural processes. They dichotomized the results of their bibliographic search into studies focusing upon general processes influencing social systems, and those dealing with specific behaviors within sociocultural contexts.

Survey Constraints

Several characteristics distinguished the review of the literature conducted by this author from those mentioned above, concerning the computer simulation of human behavior. First, the survey focused principally upon computer simulation studies which attempted to model primarily or secondarily social structures or processes; that is, the behavior or performance of two or more people who aggregated or interacted. Second, the literature search dealt exclusively with those simulation studies in which psychosocial parameters or variables were indubitably and intrinsically captured or manipulated by the computer models themselves. Third, a two dimensional scheme was selected for classifying the identified investigations based solely on arbitrary and pragmatic reasons. The first dimension considered the scope

of the specific studies, whether they concerned themselves with micro- (small groups and organizations) or macro- (large organizations or societies) social systems. The second dimension considered the nature of the specific studies, whether they concerned themselves with theoretical or operational social systems. Table 1 depicts how known simulation experiments which met the survey constraints, were sorted according to the adopted classification scheme, to give some order to the findings of the reported review of the literature.

Micro-theoretical Studies

Several computer simulation studies have been reported in the research literature regarding theoretical aspects of small groups and organizations. Brightman and Kaczka (1973) demonstrated the desirability and feasibility of computer simulation as an extremely effective methodology for psychosocial research, and as an advantageous adjunct to ordinary organizational investigatory techniques. They related successfully via computer simulation, supervisory style and worker interpersonal orientation to productivity, worker job satisfaction, and group cohesiveness. A computer model was constructed employing each work group member as the basic unit. Individual workers were represented by a vector of attributes (rank, power, and productivity). These worker characteristics were essentially dynamic since they were instrinsically and sequentially generated by the simulation. Also, every worker was characterized by two static properties which represented his potential rewards on the job. These consisted of friendly co-worker and supervisor relationships. Brightman and Kaczka created a dynamic model which was consonant with the findings of both laboratory and field investigations, inorder to examine the effects of supervisory style, and worker intrinsic and extrinsic motives upon group behavior. The computer simulation model implemented had two independent variables, namely: supervisory style which was specified along two dimensions, consideration and the initiation of structure; and worker interpersonal orientation which was defined by the three dimensions of Schutz's (1958) FIRO--inclusion, control, and affection. The four dependent variables utilized in the investigation were productivity, job satisfaction with co-workers, job satisfaction with supervision, and group cohesiveness.

Brightman and Kaczka's computer simulation consisted of several programmed modules or submodels. Their communications submodel dealt with only two individuals, the focal person and the role sender. When responding to the role sender's communication, the focal person could either conform or not conform. If he did conform, then the role sender could either reward or not reward the focal person. If he failed to conform, then the role sender could either punish or not punish the focal person. The rank program module consisted of a number of conforming responses to individual initiated communications. The frequency with which simulated persons conformed to co-worker communications was used as the criterion to rank individuals. Their productivity submodel considered the production norm as a weighted average of four individual workers outputs, not influenced by co-worker productivity. Production was thought of by them as a positive function

TABLE 1

Classification of Computer Simulation
Studies of Psychosocial or
Sociotechnical Systems

Nature	Scope: Micro-	Scope: Macro-
Theoretical	Brightman & Kaczka (1973) Gullahorn & Gullahorn (1963; 1965b) Loehlin (1965) Hare (1961) Malone (1975) Roby & Budrose (1965) Marshall (1967) McWhinney (1964) Kessler & Pool (1965) Pool & Kessler (1965) Rainio (1966) Cartwright, Littlechild, & Sawyer (1971) Hart & Sung (1973)	Bonini (1964) Boguslaw, Davis, & Glick (1969) Boguslaw & Davis (1969) Cyert, Feigenbaum, & March (1971) Hägerstrand (1965) Hanneman et.al. (1969) Rome & Rome (1961, 1964) Smith (1969) Taft & Reisman (1967)
Operational	Brotman & Minker (1957) Geisler (1959) Haythorn (1962) Coleman (1961) Waldorf & Coleman (1971) Kaczka & Kirk (1971) Ozkaptan & Getting (1963) Siegel (1961) Siegel, Wolf, & Lanterman (1967) Siegel & Wolf (1969) Siegel, Wolf, & Cosentino (1971)	Pool & Abelson (1961) Abelson & Bernstein (1963) Levin (1962) McPhee, Ferguson, & Smith (1971) Cornblit (1972) Cogswell (1965)

of the likelihood with wich workers conformed to the supervisor's communications. Their probability revision module was based on Rotter's (1954) social learning theory. In other words, the likelihood that a behavior occurred was assumed to be a function of an individual's expectation regarding probable reinforcement, and the utility attributed to the reward by a worker. The group cohesiveness submodel consisted of sociometric relationships as indicated by the number of communications among individuals, and the ratio of preferred to non-preferred outcomes, taken from some of Homans' (1950) notions. Their job satisfaction module was grounded in Vroom's (1964) multiplicative model, where occupational enjoyment was considered to be a function of not only the extent to which the job provides positive payoffs, but also the extent to which the worker values these outcomes. A string of pseudo-random numbers was used to drive the dynamics of the model. By employing computer simulation methodology, theoretical voids could easily be discovered, and field research studies could readily be utilized as "benchmarks" for model validation.

Gullahorn and Gullahorn (1963) captured and modelled in a computer simulation some of Homans' (1961) notions concerning simple social situations. Their ultimate goal was to construct and exercise a computer model in order to improve the prediction of small group performance. The program that they developed, "Homunculus", assumed that each person was an information processing organism. Many of the dynamic implications of Homans' explanatory propositions, which related the decision-making processes of individuals involved in social exchanges, were programmed into the model. Homans' theory envisaged human social behavior to be a function of the quality and quantity of the payoffs the participants expect to receive.

Each simulated person was programmed with several capabilities: "...to receive stimuli, to store stimuli in memory, to compare and contrast stimuli, to emit activities, to differentiate reward and punishment, to associate stimulus and response, to associate response with reinforcement, [and] to predict the probability of reward resulting from each response he contemplates." The computer language employed was a list processing language, Information Processing Language, Version V. Within their computer model, each person was depicted as a list structure. Among the data included in the descriptive list for each person were "...his identity, his abilities, his relative and absolute positions in various social groups, his image lists of his reference groups, and his image lists of other group members." By expressing and exercising psychosocial theory as a computer model, complex social situations are reduced to simple symbol manipulating processes, which facilitate the understanding of interpersonal dynamics. Also, the Gullahorn's reported another study (1965b) using "Homunculus", where computer simulation was employed to examine decision-making in a role-conflict dilemna. Input data for this simulation was selected from a previous investigation utilizing a questionnaire to study the impact of personal preference and perceived reference-group pressures upon choices concerning role performance. By formulating this study as a computer simulation, the theoretical implications of verbal propositions could be

explored more comprehensively and precisely, than linguisticly expressing these conceptual processes.

Loehlin (1965) developed a computer simulation model of personality, which he called "Aldous". It was comprised of three primary modules that mimicked various aspects of human behavior, specifically, action preparation, emotional reaction, perceptual recognition, plus short- and long-term memory. Loehlin juxtaposed two copies of Aldous within the computer and empowered them to interact. In addition to the two personality models, a third program was also placed in the computer which symbolized not only the experimenter, but also the environmental situation constraining the probable payoffs of various interaction alternatives. Three social consequences were permitted within this model: (1) satisfaction, which resulted from the other personality model's positive approach, (2) frustration, which resulted from an incompatible response to a positive or negative approach, and (3) injury, which resulted from the other personality model's attack. Each social interaction sequence was initiated by the control program randomly inducing one of the models to act. Following each interaction, this same program computed the payoff for each copy of Aldous. In several studies, the starting personality characteristics of these models were manipulated, i.e., attitudes, traits, and roles, as well as situational variables. The resulting patterns of the simulated social behaviors resembled closely real human interaction sequences, since they were complicated, phasic, and sensitive to the same variables as ordinary people.

Hare (1961) employed computer simulation techniques to investigate interaction in small groups, by capturing important properties of Bales' (1959) program outline for the "Interaction Simulator". The objective of this difficult task was to simulate both the content and process of small group discussion, utilizing as input the personality characteristics of the members, plus the conversational topic. The strategy for model construction was to write in machine language programs which mimicked initially only individual task activities. Subsequently, these were concatenated in order to simulate group behavior. Also, modules were added which even duplicated the effective behavior of task group members. The simulated group consisted of five members who were undergraduate college students. Their discussion task was to predict the responses of an unknown student on the Bales-Couch Value Profile. Hare gave these subjects answers to five items from the profile, and then requested them to predict the responses of an unknown student to ten additional items.

For the computer modelling part of the study, Hare attempted to simulate with his model the process, which each group member employed in making a decision regarding a profile item, prior to pronouncing his prediction to his colleagues. Each member's judgmental policy was presumed to be captured and represented by factor loadings, reflecting distinct dimensions of item content. Afterwards, another computer model was constructed to

represent the group's judgment for each profile item. This was accomplished by assuming that their consensus was reflected in the average of the individual member's judgments. The model output was comprised of the true answer, the estimate, the average discrepancy, and the response set. In order to evaluate the effectiveness of these computer simulations, the predictions produced by the model were compared with those made by the real group members. Hare reported that a discrepancy seemed to exist between simulated and actual individual and group performance.

Malone (1975) demonstrated the feasibility of employing computer simulation methodology to study general models of two-person interactions. A computer model, which used Leary's (1957) theory of personality as a basis, was produced. According to its speculative foundations, this programmed paradigm presumed that all interpersonal responses can be placed into one of sixteen classifications. There are two major dimensions of this response space: dominance-submission and attack-affection. For conceptual purposes, the categories were located between these primary dimensions on the surface of a circle. Leary's theory emphasized that every individual has a predisposed tendency to favor specific response categories rather than others. Leary mentioned that: "Most everyone manifests certain automatic role patterns which he automatically assumes in the presence of each significant 'other' in his life. These roles are probability tendencies to express certain interpersonal purposes with significantly higher frequency." The sixteen behavioral classifications were structured as segments of a circle by Leary in order to draw attention to his principle of "reciprocal interpersonal relations." That is, a stimulus located in one segment typically elicits a response from another segment, which is positioned immediately across the major horizontal dimension from the stimulus. Based upon these speculations, Malone designed his simulation model so that any interpersonal response could be represented as any one of sixteen behavioral classifications, which could vary in intensity from one to four. Consequently, since he emphasized role-determined behavior, any individual's role was depicted as a probability distribution across the sixteen behavioral classifications.

For the simulation a response-generating function was designed which was grounded in the principle of reciprocal interpersonal relations. This was formalized for the computer model as a transition matrix. The elements of this matrix represented the probabilities that the next response emitted by an individual will be in some category. This presumed that the other person's preceding response was also positioned in some category. Therefore, at any given time the computerized paradigm would have to keep track of two probability distributions: "(1) the person's role distribution and (2) the distribution determined by the immediately preceding response by the other person." A response category was chosen by averaging these above distributions in order to derive another probability distribution, which was used in conjunction with a random number generator. The intensity of a selected response varied directly with the probability of the response

category which was chosen. Consequently, only the behavioral categories determined the resulting interpersonal interaction, since response intensity was a scaled version of the chosen category's probability. Malone did not employ Leary's learning theory, but rather modern learning theory in his computer model. This was done so that a person's response probability in a given category could be considered as increasing if it was positively reinforced, and decreasing if it was negatively reinforced. A reinforcement matrix was established which assumed that a response was positively reinforced if it was followed by its reciprocal behavior (dominance by submission), and negatively reinforced if it was followed by a remote behavior (dominance by compromise).

The computer paradigm was programmed in PL/1, and it was exercised on an IBM 370/155. Hypothetical persons were defined by specifying role distributions for each of these individuals. Different interpersonal interaction schemes were established--normal/normal, normal/sadist, normal/masochist, and normal/paranoid. One of the primary findings consisted of all simulated roles becoming complementary during the course of the modelling. That is, "...the characteristic responses of each role are those that evoke the characteristic responses of the other role,..., and that are also reinforced by those responses...." Apparently, these theoretical people provoked one another into "repetition of reciprocal responses." This strengthened not only Leary's tenets, but also Malone's model. The simulation was validated by using a Turing-like test. It was concluded that simulation techniques can be utilized for the exploration and extrapolation of theory.

Roby and Budrose (1965) demonstrated the complementary instrumentality of laboratory and computer simulation studies. In other words, by comparing and contrasting the consequences of ordinary experimental investigations with the results produced by a computer model, substantive situations are easily identified and clarified, as well as subjects for subsequent research. Roby and Budrose concerned themselves with small group performance on a pattern recognition task. They manipulated the complexity of the patterns, and the number of group members who could immediately identify the patterns. The task consisted of detecting specific sets of two-digit numbers which might appear on the member's collective displays. The simulation experiment mimicked a conjectural group of four persons, each possessing a specific item of information. Pattern identification was operationally defined such that each element in the sequence was accumulated by a group member with a template. Communication within the group was assumed to be random and unidirectional. The model was programmed so that, within each time segment, a message was produced and transmitted by a simulated group member to anyone of his colleagues. The message contained a single group member's updated data regarding unique items of information, but not any template facts. Also, the program was written to accommodate the accumulation of information by any one member. The output data generated and recorded by the computer model were the mean number of trials for successful pattern recognition. Some discrepancies were found between the real empirical investigation and the simulated study.

Marshall (1967) employed computer simulation to develop a general model of human behavior in communications networks. This technique was utilized in order to depict a number of network configurations, plus groups of various sizes. There was no empirical evidence which demonstrated similar communications behavior between small (five or fewer members) or large (twenty or more members) groups, since most of the reported studies have been performed with groups of fewer than five members. Consequently, computer models were constructed of Bavelas-type (1950) communication network investigations. The primary properties of Marshall's model were "(1) [a] set of messages which lead to solution of the problem and influence behavior patterns; (2) [a] set of rules which provide for probabilistic responses to instruction messages...; (3) [a] set of initial program parameters, some of which are altered during the course of simulation...." Although computer simulation successfully imitiated the behavior and performance of five-man "chain" networks, and six-man simple "Y" networks, it did not mimic very well the behavior or performance of complex six-man networks. This study established the feasibility of simulating via computer the results of experimental investigations, and predicting with computer models probable fruitful paths for future research with human subjects.

McWhinney (1964) had actually used computer simulation techniques to imitate communications network experiments before Marshall. McWhinney thought that this methodology was an excellent environment in which to examine extrapolations from empirical data. He, as Marshall, also simulated human behavior in Bavelas-like communication networks. However, McWhinney assumed that each group member was rational; and he expressed this rationality in two behavioral constraints. His presumption of "local rationality" limited a simulated member from sending a message to another, unless the former possessed information he knew the latter did not possess. Also, McWhinney assumed that a group member would include all the information available to him when formulating a message for transmission.

The computer model was programmed in a language called "THAT", an algebraic compiler which directly permitted Boolean operations. The simulation depicted groups of subjects, and their artificial constraints and memories, in a series of Boolean square matrices. McWhinney mentioned that "[o]ne matrix represented the information state of all the members, another the constraint of local rationality, a third provided a particular item of past history, a forth, currently maintained behaviors...." Two types of runs were executed with the simulation. Those exercises with the "learning" module loaded, simulated those behaviors ordinarily found in experimental groups participating in communication network investigations. Those exercises without the learning module loaded, simulated those behaviors manifested only under the assumption of local rationality. The criterion measures used to assess artificial group performance were (1) the number of messages required to complete a task during each trial, and (2) the time it took the simulated members to do this. The match was excellent between the artificial and empirical data for the "circle" network, but only fair for the "all-channel" network.

Kessler and Pool (1965) and Pool and Kessler (1965) described their "Crisiscom" (communication in a crisis) computer simulation effort, which modelled dynamically the confrontation of national decision-makers in a crisis situation. Once interaction was initiated between the decision-makers, it was continuously maintained cybernetically. The computer model was developed such that each decision maker "(1) receives information about his environment; (2) incorporates this information in ways which are a function of his own cognitive structure and sociopsychological processes; (3) generates new information from his cognitive structure and outputs it into the environment." "Crises" were characterized as situations in which information was produced and exchanged at very rapid rates, i.e., a condition of information overload. This simulation represented, to some extent, the psychological process of "selective perception" by having the artifical decision makers differentially weight input information as it was incorporated into their cognitive structures. It was an attempt to have the model mimic the psychological mechanisms which affect how the decision makers process information, and how they conjure idiosyncratic images of the phenomenal world.

The simulated components of each decision maker's cognitive system were messages which reflected the interpersonal relationships among prominent international figures, e.g., the President of the United States and the Prime Minister of Great Britain. The artifical relationships among decision makers were constrained to affect (the attitudes one actor had toward another) and salience (the importance of an actor or relationship). Each simulated decision maker had an incomplete and imperfect picture of the relations among the actors, due to incoming information overload. Consequently, each decision maker was "selectively exposed" to only some messages, which distorted his perception of the simulated world.

The scenario used in the simulation was produced by going through historical documents. Each incoming message consisted of a relationship between two countries; each message received by a decision maker was distorted by bias modules, which incorporated concepts from cognitive balance (Osgood & Tannenbaum, 1955) and dissonance (Festinger, 1957) theories. The cognitive structure of each decision maker depicted in the simulation was comprised of two priamry components. One of these segments was an "affect matrix" which reflected how the decision makers felt about one another. The other segment was "...a hierarchical set of list structures, the items on the lists being messages. The hierarchy was composed of: (1) an attention space, (2) a pressing problems list, (3) a put-aside list, and (4) memory." Initially, only the bias and distortion modules were performed by the computer model, which necessitated placing a man in the loop to simulate the decision-making processes. Subsequently, they mentioned, via personal communication, that the entire exercise was totally computerized for simulation purposes.

Rainio (1966) designed and discussed two computer simulation experiments. The first imitiated sociometric changes which initiate from a specified sociogram; the second estimated the abstract sociometric structure of a group. Based upon his stochastic theory of social interaction, Rainio posited several presumptions including one concerning social contact-making probability. That is, if two individuals find their initial contact rewarding, then the probabilities with which they will contact each other again can be specified according to the Bush and Mosteller (1955) learning model. For the first investigation, friendship choices were produced by specifying for a group, several sociometric matrices of contact-making probabilities at certain time intervals. Contact decisions were determined not only in line with the learning model, but also corresponding to the time segment between consecutive sociograms. The following were assumed for the first simulation study: "...[1] to be a contact in the sense of the model, the meetings must obviously involve some relatively significant exchange of opinions..., [2] ...the probability of contacts is markedly higher in the directions of friendship choices than in indifferent directions..., [and 3] ...the probability of expressing Opinion A was...initially 0.5 for each individual."

Rainio had obtained three sociograms of a group of twelve girls in junior high school, taken at approximately six-week intervals. He then constructed and executed a computer model to mimic the sociometric contacts of these students. The computer simulation was driven stochastically to imitate fifty encounters. The program apparently altered the artifical contacts such that if both simulated individuals were reinforced positively (negatively), then the probability of them making second contact increased (decreased). After cycling the simulation program ten times, the empirically acquired and theoretically generated sociograms were compared, relative to the stability of choices and the changes in the choice relations. Rainio revealed that the fit between the realistic and artifical data was quite good.

For the second experiment, it was assumed that sociometric choices were produced by taking as a point of departure, a "homogeneous matrix of contact-making probabilities." By using this matrix as initial input, the simulation program could generate randomly a number of contacts which were likely to become relatively stable over sufficiently long time periods. This other investigation was conducted, in order to determine the theoretical sociometric structure resulting from the computer simulation "...if the matrix of contact-making probabilities is initially fully symmetric but the distribution of the learning coefficients agrees with the [consequences of his] laboratory experiment." It was presumed in this experiment that (1) the artifical individuals were equally likely to become a contactor, (2) the probability of being an initiator was arbitrarily defined as 0.033, (3) the likelihood of contacting any given individual was initially 0.034, and (4) the probabilities exceeding a threshold value of 0.109 specified friendship choices. Every execution of the simulation program imitated 1200 encounters. After each sequence of 300 mimicked meetings, the produced contact probabilities were used to depict the speculative

sociograms. Input data had been obtained from nine junior high school classes--four of boys and five of girls. Rainio found that simulated clique sizes corresponded more markedly with the actual clique sizes of the males than the females. Also, he interpreted the data as suggesting that the stochastic theory of social interaction, could be readily elaborated into a satisfactory speculative structure of the formation of sociometric choices.

Cartwright, Littlechild, and Sawyer (1971) employed computer simulation techniques to investigate the amount and allocation of satisfaction which are affected by three decision criteria, and by different "individual preference structures" existing within a group. The collective decision criteria, which were used, determined how individual preferences were pooled to specify a payoff for the group. That is, these decision rules were considered to indicate how individual preferences were satisfied, when they were coalesced into a collective judgment. "The first criterion regards simply the direction of a person's preference (for, against, indifference). The second criterion considers preference on a scale from -9 to +9. The third criterion uses the same scale, but minimizes a squared function that gives more weight to extreme preferences." Apparently, the first decision rule designated a group judgment in which all individual inputs were weighted equally. The second and third decision rules considered varied intensities and differential collaboration among members. The objective of the study was to determine how "aggregate welfare" was affected by different decision rules. These represented how a group member favors or opposes an issue, and how the intensity of a member's preference influenced this behavior. For each of the three decision rules, and for distinct preference structures, computer modelling was used to ascertain not only the average amount of satisfaction generated by each rule, but also the distribution of satisfaction among group members.

The simulation was designed to produce "individual preference matrices", which differed in magnitude, distribution, and agreement among group members regarding certain issues. The three decision criteria were applied by the model to each cluster of generated preferences. The paradigm produced a continuum of intensity preference for each issue extending "from strongly opposed through indifferent to strongly favorable." Individual preferences varied for each issue. For the preference matrix, the model indicated a particular payoff for each issue by specifying "the utility of possible outcomes." A member's preferences were indicated by employing various weights which defined a specific utility function. The salient results consisted of the following:

"1) Only a small potential increase in mean utility can be expected from any vote-trading, bargaining, or other scheme that departs from the simple rule that each person votes his own preference on every issue.

2) Smaller numbers of persons and issues permit higher mean utility, but distribute it less evenly.

3) When the number of issues and persons is small, a substantial gain in the equality of distribution can be obtained with a very small sacrifice in total utility.

4) The largest increment to mean utility and to equality of distribution occurs in the difference between moderate concensus and random agreement rather than in the difference between moderate concensus and complete uniformity of preferences.

5) The above results hold across three symmetrical distributions that represent extremes in degree of centrality or distribution of preferences."

This study demonstrated the feasibility of employing computer simulation methodology to study speculative small-group behavior.

Hart and Sung (1973) designed and executed a computer simulation of decision making in a triad. Emphasis was placed upon member's satisfaction with the group's decision and the difficulty the group had in reaching its judgment. An integral aspect of their conceptualization was preference behavior. "Since the group must arrive at a collective preference from several divergent preferences it is clear that a process by which these preferences are changed is a necessary part of a model of the group decision making process." By assuming no differentiation between preferences and attitudes, it was feasible for them to adopt an attitude change model which indicated differing preference intensities. Sherif's social judgment theory (Sherif & Sherif, 1969) was selected for this purpose, especially since it stressed ego-involvement.

The computer model was such that the preferences or attitudes of each of the three members of the group were randomly assigned, scaled values. "[T]he average distance of the three group members from the mean of the group" was used to operationalize concordance (likeness among individual preferences). Presuming that ego-involvement varies directly as preference strength, each hypothetical group member was randomly assigned a certain amount of ego-involvement. This was the means by which preference strength exercised control over the group's decision in the model. Based upon Sherif's speculations, ego-involvement was operationalized in terms of a ratio of latitude of rejection to latitude of noncommitment. It was assumed that ego-involvement was constant during group decision making. The simulation was designed to have either an authoritarian or equalitarian status situation existing within the group. Also, in the equal status condition coalitions could exist within the computer-modelled group. A coalition condition existed within the simulation when a member's attitude was within another's latitude of acceptance. Two decision rules were employed for the model--"1) majority, defined as two group members within $\pm$ 2.5 scale units in their attitudes; and 2) unanimity, defined as all three members within the same limits."

During each cycle of the simulation, the mimicked group members influenced one another until unanimity was attained. It was presumed that every member was "equally persuasive and persuasible" and that a simulated person's overt opinion actually reflected his covert preference. The simulation initiated interpersonal interaction by having a member send a message to the others in the triad. The communication consisted of the transmitter's attitude toward an issue; the impact of this message was exclusively upon the receivers. "An attitude change was a function of: 1) the distance between the recipient's position and the position of the message, and (2) the recipient's latitude configuration (itself a function of the recipient's attitude and ego-involvement). The latitudes were conceived of as directional probability regions, i.e., there were probabilities associated with positive change (toward the message), negative change (away from the message), and no change for each latitude." The consequence of a modelled coalition formation was to alter the attitude change paradigm by incrementing the likelihood of positive change towards communications originating within the coalition itself. The assumption of constant order of influence within the initiated group did not produce any indication of position bias in the power processes among the members. It was found that "...[the] main effects [were] decreasing difficulty and increasing satisfaction with increase in concordance, and low ego-involved groups exhibiting a greater increase in concordance than their high counterparts." Also, it was established that some of the results of the simulated interaction did not agree with the experimental group's performance which served as a validating base for the computer modelling.

Macro-theoretical Studies

Various investigations have dealt with the computer simulation of distinct aspects of large organizations or societies. Bonini (1964) constructed a comprehensive computer model of a hypothetical business using theoretical constructs from the sciences of psychology, economics, and accounting. He formulated his model of the firm as a structure consisting essentially of "small" decision centers or nodes. It was assumed that each of the artificial decision makers occupying these nodes had powerful pressure exerted on him in the performance of his job. Consequently, an "index of felt pressure" was defined for every decision maker within the firm. Bonini was also interested in the "contagion effect" of this pressure among the various hierarchical levels within the firm, and the impact of information regarding performance relative to standards upon perceived pressure. Thus, he manipulated the computer model by inducing "...changes in the information flow within the firm, changes in the decision rules, changes in indexes of felt pressure, and changes in the firm's environment." Bonini exercised the model over one month intervals of simulated time, and recorded the following multiple measures to describe the behavior of the firm--"...indexes of price, cost, and inventory; dollars of profits; dollars of sales; [and the] index of felt pressure within the firm."

Boguslaw, Davis, and Glick (1966) developed a social simulation called "PLANS". It consisted of "...a socio-economic model of the American society ...[treating]...that society as a complex system of social, economic, and political variables and attempts to predict the outcome of negotiations among interest groups regarding various public policies." Initially, six human subjects played roles which represented salient interest groups within society, e.g., business, military, or civil rights. These participants were required to make decisions reflecting their simulated interest groups, regarding such issues as disarmament or guaranteed income. Subjects were required to negotiate policies, and to allocate resources among them. Boguslaw and Davis (1969) attempted to simulate PLANS via computer, in order to determine to what degree their definition of the "critical" variables in this social situation, would correspond to the perceptions of actual subjects in role playing experiments with PLANS. To construct and exercise the computer simulation of PLANS, several "decision-modes" were specified which ranged from very simplistic to very sophisticated decision-making behavior.

Boguslaw and Davis programmed their computer model in JOVIAL, and made some simulation runs under time-sharing conditions. They discovered that the computer simulation of PLANS was distinctly different from the human simulation of PLANS. Although, both actual and artificial subjects' decision-making behavior appeared to be rational, realistic human subjects were "...somewhat less than maximally rational in the pursuit of their own objectives." These findings suggested that the simulated decision makers had no objectives to consider, but only those programmed for them. Consequently, these automatons automatically and undeviatingly pursued the predetermined goals, thus optimizing their decision-making behavior. Whereas, the human role players brought into the experimental situation a great gamut of "...previous dispositions, interpretations, value orientations, [and] perceptions." These seemed to lessen the efficiency of the subjects in terms of formal goal achievement. However, there was a grave concern that computer simulation by being objective, accurate, and rigorous might neglect many "informal goals and unspecified value orientations." They concluded by claiming that these subjective or unexpressed goals could be captured and specified through the utilization of "...depth interviews, projective tests, and attitude questionnaires." Consequently, these "intangibles" could readily and more accurately be incorporated into computer simulations of social behavior.

Cyert, Feigenbaum, and March (1971) demonstrated that a comparatively complex computer model of organizational decision making could be developed and exercised to produce testable and feasible forecasts of business behavior. They considered that the decision-making process of a firm consisted of nine distinct steps, namely: "...forecast competitor's behavior, forecast demand, estimate costs, specify objectives, evaluate plan, re-examine costs, re-examine demand, re-examine objectives, [and] select alternative." This speculative scheme was the logical structure upon which

they constructed an executive program to mimic organizational decision making. It was intended to produce a plausible set of estimation and decision rules for distinct types of organizations, and to model via computer the longitudinal behavior of these firms. A duopoly model of the firm was used which was comprised of an "ex-monopologist and a firm developed by former members of the established firm, 'the splinter'." The decision-making behavior which was simulated focused upon production output; and in making this decision the artificial firm had to estimate the market price for changing productions. Some of the variables involved in the simulation were "...[t]he actual change in the splinter's output during some time period; the actual change in the monopolist's output during that period; the change in the splinter's output during some time period as a percentage of the monopolist's output change during that time period." It was concluded that decision-making behavior could be much better comprehended speculatively by employing computer simulation models, since the "internal" processes of a firm could clearly and easily be captured and manipulated by computer modelling. Finally, it was affirmed that the simulation attempts were intended to be descriptive of the following: decision-making dynamics, changes in organizational objectives, alterations of forecasts based upon feedback, and variations in organizational slack.

Two investigations have been conducted and reported in the scientific literature employing computer simulation to study "spatial diffusion." This is the sequential dissemination of innovative ideas through a social system via various communication channels or networks. Hägerstrand (1965) suggested segmenting a social system into subsystems "...according to the distribution over distance of communication links." "Distance inertia" manifested itself within a population, as a function of the number of people within a regional area who normally remained closely tied to their local communication networks. Based upon these notions, Hägerstrand defined his concept of "mean information field." According to Hanneman, Carroll, Rogers, Stanfield, and Lin (1969), this construct was Hägerstrand's salient contribution to the computer simulation of spatial diffusion. They defined mean information field as "...the probability of an individual in any particular cell of this matrix [which depicts the structure of a communication network] receiving a communication message from an individual in the central cell [which depicts the information source]." It should be stressed that computer simulation of spatial diffusion, typically utilizes this notion of mean information field to forecast the path of innovative informational flows.

Hägerstrand used simulation techniques to analyze the "spread of subsidized improvement of pasture." He assumed for his novel simulation effort, "[a] model-plane with isotropic conditions as to population distribution and transportation. This was made up of square cells, used as a reference grid and mean information field...." Hägerstrand presumed that (1) the population was uniformly distributed having a fixed number of inhabitants in each cell which was isomorphic to farmland density, (2)

the simulated planes produced a "transportation surface" on which locomotion was omnidirectional without any impediments, (3) an individual's behavior remained constant from innovation to innovation, and (4) novelty of any innovation stayed fixed relative to "a state of culture." Finally, he mimicked via simulation the notion of "resistance" which was restricted to the ease of spatial diffusion, and the rate of adoption of innovative technology.

The computer modelling of the diffusion process, by employing a hierarchy of mean information fields, enables researchers to make deductions about dissemination of information, which are entirely independent of the innovations themselves. Simulation techniques empower the behavioral scientist to produce different artificial social structures, and to endow the simulated individuals within those structures with differentiating behavioral probabilities and various rules of actions. Consequently, it is a relatively simple task to employ Monte Carlo techniques to "...infuse life into the [simulated] system" in order to study its dynamics in an easily controlled manner.

Hanneman, Carroll, Rogers, Stanfield, and Lin (1969) also used computer simulation techniques to analyze spatial diffusion. Paramount to their computer model was the notion of "neighborhood effect", that is, "...the probability of an individual's adopting an innovation decreases with his spatial distance from a previous adopter." This concept was based primarily upon Hägerstrand's construct of mean information field. A programmed, essentially stochastic model called "SINDI" (the Simulation of Innovation Diffusion) was employed to mimic the dissemination of agricultural information about an innovation (2, 4-D weed spray) in a small, isolated Latin American village. It was assumed that messages concerning innovations entered externally into this social system, and that internal diffusion of innovative ideas occurred primarily through opinion leaders.

Several systemic parameters of SINDI were identified and discussed which were either arbitrarily determined, or theoretically grounded. The social system was divided into "cliques" and isolates, according to sociometric data which specified whom each village member sought for information regarding agricultural innovations. "External channels" were specified which were artificial extention service agents and school teachers; "channel orientation" was detailed which indicated the degree that an individual was directed to either external channel. "External channel contact" was defined as a function of the duration of a message through a channel, and the number of specific people reached. Also, the "probability of becoming a knower from an external channel" was expressed as a function of the amount of interpersonal communication stipulated by each simulated village member. "Local interpersonal channels" were considered to be related to the number of opinion leaders in the artificial social system; and "teller contacts" were thought to be related to the number

of reported opinion leader contacts. Lastly, the "probability of becoming a knower when contacted by a knower-teller" was a function of the "knower-teller" contacting his clique. As output, SINDI supplied the distribution of "...new knowers per time period over a series of time periods--i.e., the annual rate of diffusion of information."

Traditionally, dissemination of information is examined by studying "slices or cross-sections" of this phenomenon at one point in time. However, by employing computer simulation methodology, it was possible to capture and analyze the dispersion process longitudinally. "The 'time' dimension is the most distinctive aspect of communication dealing with innovation diffusion." Computer simulation of diffusion dynamics can easily be employed to predict the adoption of innovative ideas, to suggest strategies for implementing change cost-effectively and optimally, and to forecast future diffusion dynamics and structures.

Rome and Rome (1961) conducted a series of computer simulation studies which analyzed the dynamics and structures of immensely complex organizations. They labelled these investigations their "Leviathan studies". Dynamic programming paradigms are not conformable to the examination of complicated organizations, since they are not suited for the modeling of "multilayered hierarchical structures...univocal optimization is largely irrelevant." Consequently, "isomorphic or analogue modelling" was utilized to analyze not only arbitrary processes of production, but also regulatory controls which manage this production. An artificial firm was contrieved by initially introducing simulated individuals who had a part in production, i.e., workers, government employees, and enlisted men. A simulated formal structure was imposed upon these fictitious cadre, i.e., five echelons of command. The Rome's attempted to model via computer, the simulated organizational structure according to the amount of completion of each segmented and supervised task, or the academic specialities involved in production, e.g., engineering, mathematics, or economics. Many decision nodes were presumed in the managing pyramid through which information flows. The simulation captured and minicked the idiosyncratic characteristics of the manager at each decision node, the formal and informal organizational structures, and the "pressure" experienced by each manager occupying a decision node within the organization. This complicated firm was considered as an intricate set of simultaneous games among individuals and coalitions. In 1964 Rome and Rome reported another computer simulation employing Leviathan in which they imitated the behavior of an imagined intelligence communications and control center. The social hierarchy of this organization was regarded as a graph structure which processed a series of communiques. They synthetized, via computer, the activities of several subsystems regarding managerial decision making, strategy, and policy. Their program was modularized into compartments dealing with the network structure itself, the information which flows through this net, and the artificial activities of individuals within the communications structure.

Smith (1969) discussed the development and utilization of computer simulation for studying "accounting schemes", i.e., predispositions of a particular individual and his specific situation with regard to moving from one neighborhood into another. His computer model was primarily based upon Rossi's (1955) "push-pull" paradigm for examining why people move, and Selvin's (1960) scheme for describing leadership consequences. By simulating via computer these abstract accounting schemes, not only were survey results parsimoniously synthesized, but also implicit motives relative to moving were dynamically explicit. A mere "S-O-R" mechanism was presumed to provide the psychological dynamics involved in the decision-making behavior regarding probable moves. For the decision-making simulation paradigm, extrinically caused complaints regarding a neighborhood were weighted against the intrinsically held prejudices. If the value of this function was less than some threshold value, then no move occurred; whereas, if it were greater, then a move occurred. Smith's model of moving dynamics was comprised of potential newcomers who wanted to move in, and present residents who wanted to move out. If the newcomer could afford to move in, and if the newcomer and resident have similar socioeconomic status, then a move occurred. Smith asserted that computer simulation models of accounting schemes like these could be employed to typify neighborhoods, and to produce stable, integrated, urban neighborhoods.

Taft and Reisman (1967) described a computer model of a heuristic algorithm for "...better curricula through computer simulation selected sequencing of subject matter." They attempted to create and simulate a general learning function by clustering many relevant variables into a number of "lumped parameters". For example, educational potential--the mastery which a learner has reached relative to an initial foundation--was defined as a multivariate function of student type, subject matter, instructional method, cumulative learning time, forgetting time, and number of repetitions of subject matter. Students were categorized according to high, average, or low learning ability by utilizing intelligence quotient, cumulative grade point average, College Entrance Examination scores, and counselor's recommendations. Subject matter was classified into levels of complexity, and instructional methods were classified into prevalent procedures currently being implemented in the school. Cumulative learning time and forgetting time were considered as the amount of time specific material had been studied in the classroom, and the amount of time specific material was not studied in the classroom, respectively. Their heuristic algorithm was programmed in Fortran IV, and it could easily schedule courses for the duration of a typical four year curriculum. The computer model not only considered the student as an intrinsic aspect of curriculum planning, but also synthetized several distinct approaches to curriculum planning. Computer simulation's most salient contribution to curriculum planning was a speculative structure which could clearly and easily be evaluated, verified, and developed further. Also, these simulation techniques facilitate the integration of specialized knowledge regarding curricula, e.g., human learning theory, media usage, subject matter scheduling, and student counselling and testing.

Micro-operational Studies

Many computer modelling experiments have been mentioned in the multi-disciplinary literature regarding the operational aspects of small groups and organizations. Brotman and Minker (1957) demonstrated a method for simulating via computer the operational performance of a complex communications system. To approximate the real situation as closely as possible, they attempted to incorporate within the simulation operator performance at switching centers. They not only tackled a telephone traffic queuing topic, but also considered the psychological utilities of these individuals occupying network nodes. Their computer model had the following features: "...[it] could handle any arrival time or length of call, many different communications configurations, any number of links between centers could be accommodated, [and] flexible routing plus re-routing procedures." In order to mimic human operator performance, their artificial personnel were programmed to sense a ring, to converse with the calling party, and to plug-in to the next operator. The multiple dependent variables of their simulated investigation were: "...per cent of total running time the station lines were used, number of calls encountering an all-busy condition, plus per cent of the total running time that each operator was busy serving calls, average number of persons waiting for the operator, [and] total number of lost and completed messages."

Geisler (1959) employed computer simulation methodology to integrate a missile squadron's physical, organizational, and communications subsystems into an effective and efficient entire system. Monte Carlo techniques were utilized to investigate what properties of the squadron's logistics structure could be altered to minimize support costs, and to maximize organizational effectiveness. Geisler stated that, in this environment, computer modelling could readily plan a paramount complementary role to man-machine simulation in the design and the development of compatible and complete organizational systems. The Monte Carlo model of the squadron mimicked malfunctions of its missile components, which in turn demanded logical, logistic support. As missile malfunctions were randomly generated, the model determined whether the personnel skills, the proper equipment, and the spare parts were appropriately available in the simulated system. The delay times in providing the proper support were also included in the model. He not only employed simulation methodology to determine the number of its launch complexes and human resources, but also to determine the alterness of the squadron and the effectiveness of its support system. The computer model optimized these factors, plus "... the total system cost per alert hour", by manipulating material, communications, and control subsystems.

Haythorn (1962) discussed a futuristic program of research, which at the time was very avant-garde. He attempted to synthesize via computer simulation some of the data which were then available, regarding the degree to which group effectiveness was determined by various clusters of personality characteristics of its members. The objective of this formidable

endeavor was to ascertain accurately using simulation, the myriad implications of group composition upon the performance of several tasks. By doing this, Haythorn hoped to extrapolate from earlier empirical research findings, to future performance situations. He was particularly concerned with small group effectiveness within weapon systems, especially, the effects of social isolation upon task performance. Several aspects of personality were considered which affected group composition, namely: dominance, nurturance, cognitive style, and introversion-extraversion. Tasks were identified which will have to be performed in future weapon systems, e.g., monitoring radars and communications and maintaining group satisfaction and cohesion. Events external to a task group were indicated which will probably place immediate demands upon it, e.g., an incoming sonar signal. Finally, those endogenous events affecting personnel performance were identified, e.g., signal detection. The models were programmed in Simcript. Haythorn has revealed to this writer, via personal communication, that certain aspects of this tedious endeavor are still being further refined and developed.

Coleman (1961) utilized simulation techniques to study group stability, reference-group behavior, and clique determination in triads. The computer model produced dynamic and stochastic interaction within these three-person groups as a function of past positive or negative reinforcements. Sociometric data were employed in order to cluster groups of high school students into smaller cliques. However, due to the very large number of students, the typical technique of matrix multiplication could not be applied parsimoniously. Therefore, simulation techniques were used which iterated over time, and placed each person into cliques which were psychologically close. As iterations continued, the closeness among clique members converged to a minimum, and the simulation ceased.

Waldorf and Coleman (1971) demonstrated the feasibility of using computer simulation procedures to study social influence processes in loosely structured social systems. Specifically, these scientists investigated friendship relations as they impacted upon trends toward attitude consistency. Survey data were initially analyzed from ten different high schools in the Chicago area. Each individual was regarded as a member of a dyad, who either frequently changes his own attitudes to be consistent with his colleagues, or frequently changes his own attitudes to be inconsistent with his colleagues. The computer model considered the attitudes of both dyadic members at some time, the attitudes of only one of the members at some second time, and the probabilities of attitude change at the second time for both members. Using these input data, their simulation model could easily forecast the member's attitude change, if any.

Kaczka and Kirk (1971) explored by employing simulation methodology the impacts of managerial climate (employee-oriented or task-oriented) upon organizational performance. They affirmed that a field study, in addition to being extemely expense and impractical, was highly likely to be confounded with many intrinsic as well as extrinsic uncontrolled variables. Their computer model was designed and developed to establish the feasibility of integrating knowledge about small-group behavior with

the behavioral theory of the firm (Bonini, 1963; Cyert, Feigenbaum, & March, 1959). The computer model included not only artificial industrial task groups, but also managerial personnel--upper, middle, and lower. These subsystems were linked together for the simulation exercise by control and information networks, which were analogous to realistic and theoretical business operations. That is, the simulated model was an amalgamation of experiential data from actual business firms, empirical facts from published professional reports, and theoretical extrapolations from Bonini as well as Cyert and his colleagues. For the simulation experiment five dimensions of managerial climate were specified:

"1. Grievance behavior. The percentage of grievances submitted settled by foremen and superintendents.

2. Cost emphasis. The weight given to cost performance by superintendents in the evaluation of foremen and the percentage of deviation of actual costs from budgeted costs that management regarded as tolerable.

3. Leadership style. The percentage of working time devoted to employee-oriented leadership by foremen and by superintendents.

4. Congruence of leadership style. The differences between leadership styles employed by foremen and by superintendents....

5. Attitudes of industrial engineering departments. The percentage of tight work standards loosened or the percentage of loose standards tightened by the industrial engineering department."

The performance of the simulated firm was evaluated by employing multivariate criterion variables. Kaczka and Kirk measured gross profit, sales exceeding cyclical changes, ratio of sales to inventory, unit cost, group pressure, and group cohesion.

Ozkaptan and Getting (1963) conceptualized and exercized a computer model designed to synthetize psychological, physiological, and physical parameters impacting upon prolonged space-mission performance. They strongly suggested that a simulation of this sort could easily be used to design and test a total system package, without incurring the infinite risks or costs involved in man-machine simulations, or the actual missions themselves. Their model incorporated many major variables--"...resources (man, machine), limitation of resources (support requirements, stress causative factors, equipment realiability), cost (weight, volume, development time), [and] return (reliability, accuracy, precision time)." The computer model was modularized into many man-machine tasks, and it specified the appropriate parameters defining task performance (e.g., precision, accuracy, reliability, time) and penalities (e.g., cost, resources, mass). The artificial tasks to be performed were selected for the simulation program by Monte Carlo techniques. The stress model was segmented into several submodels, specifically: "...(a) environmental stress--induced by the external environment; (b) procedural stress--induced by the physiological state of the organism resulting from the effects of his performance; (c) random-environmental effects--certain chance occurrences such as accidents or meteorite penetration, plus individual differences

in [human] performance variables." Ozkaptan revealed, via personal communication, that some segments of their proposed computer model were actually exercised, and that although the overall approach was pragmatically and speculatively sound, the utilization of computer simulation techniques in this matter was probably too futuristic for the time to permit complete implementation.

Siegel and his associates conducted a series of studies in order to determine the feasibility of using computer simulation techniques to design, develop, and evaluate man-machine or sociotechnical systems. In 1961, Siegel reported the development of "psychomathematical" paradigms which could be programmed and exercised to simulate the behavior of systems with one or two human operators. The objective was to enable systems designers during the early stages to determine quantitively: (1) the likelihood of successful task completion by typical operators, (2) the extent of psychological stress induced in ordinary operators by information overload, and (3) the distribution of human errors as a function of several stressing constraints. The computer model examined such variables as: "...man's reaction times, his ability to stand stress, his breaking or confusion point (stress threshold), his ability, [and] team cohesiveness." "Stress threshold" was considered as the point where human performance is irregular to such an extent that the likelihood of successful task completion is quite low, while the likelihood of prolonged operator responses is quite high. The performance of each operator was segmented into "subtasks" which served as the bases of the modularized computer model. For each simulated subtask, the program regarded: "...the average subtask execution time, the probability of performing the subtask successfully, an indication of whether or not the subtask is essential, a waiting time before which the operator could not begin the subtask, and an indication of the subtask to perform next in the event of either success or failure of the subtask." Siegel's simulation model computed sequentially four factors for specific subtasks: (1) psychological stress was calculated as a positive function of the amount of the subtask the simulated operator still had to complete, (2) execution time was determined by employing Monte Carlo procedures from a truncated normal distribution having parameters based on stress, (3) likelihood of successful execution of a subtask was defined by operational stress state as well as stress threshold, and (4) time constraints were established in which the operator must complete the subtask. Also, the computer model was validated by comparing its output relative to realistic operator performance data for several tasks, e.g., landing an aircraft on a carrier, and launching an air-to-air missile.

For similar scientific speculations, Siegel, Wolf, and Lanterman (1967) constructed and exercised a computer simulation to forecast crew performance, productivity, morale and cohesiveness. They attempted to validate the model against the actual performance of three departments within a Fleet Ballistic Submarine--weapons, operations, and navigation. It was implied that the tasks of simulated crew members within these departments, were mimicked by the model in a manner resembling the previously mentioned Siegel study. The criteria data for the validation exercise were obtained from formal interviews with officer, chief, and

petty officer contingents. Siegel and Wolf (1969) reported another simulation study in which they considered a whole gamut of many "qualitative" small-group variables, namely: norm sending, cohesion, status, leadership, stress, information flow, group composition, and task performance. For their "quantitive" small-group computer model they dealt with equipment, mission, and personnel parameters; individual characteristics; crew formulation, morale, and cohesion; communications, psychosocial, crew, and environmental efficiency; and task execution time. Initially, an analogue of an operational Naval system was analyzed, which was to be simulated, in order to ascertain its salient attributes with respect to crew composition, mission assigned, and type of technology. The model was capable of simulating not only the selection of crew members by classification and skill level, but also the crew's daily performance of each central task. The computer model mimicked and manufactured measures of: (1) execution time for the crew to complete a task, (2) group performance efficiency as defined by the number of intracrew communications, (3) specialty proficiency of crew members, (4) environmental stress due to emergency situations and confinement, and (5) psychosocial interactions among the crew members.

Siegel, Wolf, and Cosentino (1971) developed and exercised a computer model to mimic the behavior of sociotechnical systems controlled by crews consisting of four to twenty members. The simulation captured and manipulated many performance and psychosocial parameters regarding learning and reinforcement, personality and aspiration, leadership and motivation, and psychological and physical factors. Like their other simulation exercises, data indicating personnel performances, operated equipments, and environmental emergencies for each simulated task were utilized as input for the computer model. These specific factors were identified as being incorporated within the computer model: (1) psychological variables--operator competence, work rate, physical capability, operator fatigue, and stress tolerance; and (2) operational variables--task essentiality, performance time constraints, quantity of consumables, and additional task demands. Their stochastic model was segmented according to the following programmed modules--crew composition, task generator, crew selection, performance simulation, psychological profile up-date, and data display. It was suggested that the model could be employed for forecasting the likelihood of successful mission completion when the tasks are very difficult and the psychosocial constraints are very demanding. Finally, the model was actually validated against data derived from a dangerous Viet Nam river patrol mission.

Macro-operational Studies

Several computer simulation studies have been reported regarding the operational characteristics of large organizations and societies. Pool and Abelson (1961) conducted a computer simulation during the presidential elections of 1960 which was referred to as the "Simulmatics Project". The purpose of this project was to demonstrate a new methodology for processing poll data and for predicting probable voter behavior. That is, Pool and Abelson wanted to be able to forecast swiftly the immediate impact of distinct, controversial, and salient issues upon the voting

public. This endeaver was begun by re-analyzing archival Roper poll results which were clustered or reduced to represent 480 distinct voter types according to specific socioeconomic characteristics, e.g., "Eastern, metropolitan, lower-income, white, Catholic, female Democrats". Fifty-two political "issue clusters" were then identified which described crucial attitudes toward e.g., foreign aid, McCarthyism, political parties, and the United Nations. These data defined the dimensions of a 480 x 52 matrix, which served as a potent "data bank" for facilitating the examination via computer simulation of speculative campaign strategies.

Concentration was directed primarily upon the impact of salient religious issues (Kennedy vs. Nixon) on a state-by-state basis. Because of small sample sizes, synthetic states were established based on estimates of the number of individuals of each voter type within them. A simulated state was defined as "...a weighted average of the behaviors of the voter types in that state, the weighting being proportional to the numbers of such persons in that state." In order to make this a feasible specification, it was assumed that voter types were identical across states, and that distinctions among states were due to differences in distributions of voter types. The processes of "cross-pressure" derived from previous poll studies were incorporated within the computer model. Thus, by specifying cross-pressures for voter types, it was presumed that an accurate estimate could be made of voter behavior or "shift" at the polls. As a means of capturing and exercising these dynamics within the simulation, a 3 x 3 matrix was defined where one dimension was religion (Protestant, Catholic, Other) and the other dimension was party (Republican, Democrat, Independent). For example, previous data demonstrated that "Protestant Republicans" did not experience any cross-pressure regarding Nixon since, at the time, these voters had no evidential dislike of him. Consequently, it was reasoned that these voter types had no manifest impulse for modifying their poll behavior. It was proudly pronounced that the simulated results closely approximated the actual election outcome. The computer model not only predicted the vote for each state, but also rank-ordered them according to how well each candidate was expected to do in each state. It was affirmed that the correspondence between the actual and artificial Kennedy vote was quite close ($r = .82$). One of the salient aspects of the Simulmatics Project was the demonstration and verification of using survey data in conjunction with computer simulation techniques to forecast social behavior based upon past attitudes and actions.

Abelson and Bernstein (1963) developed a computer model of community referenda concerning specifically "fluoridation controversies". The behavior of actual individuals which was based upon survey data was imitated by their simulation. For each person, the computer model incorporated the following input data: "...demographic characteristics, predisposing experiences and attitudes toward the referendum campaign arguments; frequency of exposure to the several news channels; attitudes toward well-known persons and institutions in the community; knowledge and acceptance of various standard assertions on the referendum issue; frequency of conversation about local politics; and demographic characteristics of

conventional partners; [and] initial interest in the referendum issue; initial position on the issue; and voting history in local elections." The computer model mimicked the dynamics by which these individuals could easily change their attitudes toward the referendum controversy. It was assumed that these attitudinal alterations could be induced by either exposure to mass media, or conversation with biased individuals.

For each simulated week, the model was programmed to expose, according to changing probabilities, each artificial person to certain communications channels, and consequently specific assertions. Affirmations were accepted by these artificial agents, as a function of the following: "...attitude toward the communications 'source', previous acquaintance with the assertion, congeniality of the assertion in terms of special predispositions, and position on the referendum issue." After exposure to these assertions, the computer model simulated a conversation between persons to mimic reactions to these claims. The analogue was programmed to elicit responses to the artificial assertions based upon compatibility of conversational partners regarding ideology, familiarity with the affirmation at some prior instance, and posture on the present topic. The computer model imitated the campaign by cycling through elapsed weeks, and by disclosing to each artificial person media channels as well as conversational partners. The dependent variables output by the simulation model were (1) stand on the issue, (2) inquisitiveness about the topic, and (3) approval of several assertions about the issue. The results of this study strongly suggested that computer simulation techniques readily provide the means of "...uniting theories of individual behavior with theories of group behavior."

Levin (1962) developed a computer simulation to imitate the influence process within adolescent peer groups, concerning the choice of political party. Typical, analytical techniques have undeniably constrained scientists to focus exclusively upon the static aspects of influence, and not the dynamic characteristics of this phenomenon. Consequently, computer simulation methodology was employed to mimic the forces of the influence process. The programmed paradigm had two components, one having a micro-function and the other having a macro-function. Levin stated that "[t]he micro-function [was] a stochastic model of the interaction process, similar in structure to the stimulus-sampling models of mathematical learning theory--however it assumed a continually changing stimulus distribution. [T]he [macro]-function translates the micro-function onto the [aggregating] level by placing the influence of the individual interaction in the setting of the social system, allowing influence to flow in many directions and through many channels...." It was reported that two preliminary runs were made with the programmed paradigm using, as input, data from a high school in Illinois. The simulation program demonstrated some promise, since the model's output corresponded to actual adolescent preference about 59% of the time.

McPhee, Ferguson, and Smith (1971) constructed a simplistic computer model of individual voting behavior, which could easily be extrapolated to encompass a multitude of voters in distinct communities over several

generations. It was presumed that decisions regarding balloting behavior were acquired over several elections through a slow process of "political socialization", rather than through a single campaign. Consequently, the simulation resembled typical psychological learning models, where effects appear to be cumulative. The program depicted three processes, specifically: (1) responding to extrinsic political stimuli, (2) influencing of individuals within the immediate social environment, and (3) learning partisanship longitudinally. Political stimuli since the preceding campaign served as input to the computer model. Subsequently, the paradigm progressed to a "discussion" module, where each artificial voter, either conformed or not conformed to the pronounced opinions of another individual. This process was the basis of the simulated "political socialization" which converted a potential voter into an habitual Republican or Democrat. In order to run the simplistic simulation, it was presumed that the proportion of votes for a specific party remained constant for past time intervals, despite voters turning over. The model was used to study shifts in voter behavior in 1960, during the last month of the Wisconsin presidential primary among Kennedy, Humphrey, and Nixon. By using simulation techniques, it was possible to analyze and synthetize complex voting processes which were not amenable to normal verbal and quantiative methods.

Cornblit (1972) constructed and described a computer model to examine coalition formation and separation among social actors, and relationships and characterizations which distinguish these entities. Social actors were defined as "...a set of individuals, an institution, or any other social unit which is considered relevant for the interpretation and explanation of events." It was intended to formulate a universal framework for analyzing political processes--past and present. Initially, an uprising which occurred in a few areas of Peru and Bolivia about 1780 was focused upon. The prevalent conditions in these regions were depicted by employing a whole gamut of variables which specified actor properties and relations, and hypotheses on coalition formation and alternation.

The content of the computer model was multidimensional, and it considered social actors ranging from simulated merchants and mineowners to clergy members and landowners. Each artificial actor had a corresponding set of attributes, which were mathematically expressed as a vector. Some characteristics which were constituents of the descriptive vector were organizational weight, propensity to violence, counterideology, status incongruence, social prestige, centrality of position, and evaluation of social welfare. The following matrices were used to describe dyadic relations among actors in the simulation: (1) a matrix of communications to indicate the amount of information exchange between any two actors, (2) a matrix of menaces to express the extent to which an artificial actor anticipated that its prosperity might diminish due to aggressive actions instigated by the other agent, (3) a matrix of ethnic differences to represent the ethnological distance between members of the dyad, (4) a matrix of agreement to signify the capability of the actor's interests in economic holdings, means of production, and exercise of authority, and (5) a matrix of attractions to reflect the mutual attraction between actors.

The computer simulation mimicked coalition formation by implementing three discrete steps. First, "leading actors" were selected as potential leaders of coalitions in order to imitate that, in actual politics, particular individuals act as poles which attract wide circles of the population. Secondly, the computer model formulated "first-order coalitions" consisting of one leader and one or more other members. The criteria adopted for establishing these temporary alliances were the attractions and menaces among actors. Thirdly, "higher order coalitions" were constructed using as elements first-order coalitions. Throughout the "coalition-building cycle", certain mathematical expressions were employed to "aggregate or disaggregate actors and leaders." These behavioral equations indicated how changes were produced in political phenomena--mobilization, menaces, anomie, communication, violence, welfare, and attraction--as functions of at least some of the variables mentioned previously. The many components of the computer model were programmed to interact in order to execute the simulation.

Cogswell (1965) suggested and showed that simulation techniques could be used to yield effective and efficient solutions to designing scholastic organizations, and implementing instructional media within these pedagogical institutions. He stated that computer modelling should: "...(a) make it possible to represent the progress of samples of students through any kind of school that can be described; (b) provide the capability of getting a report on changes in the students and in resources at variable time intervals; (c) permit the simulation of resource depletion and show the effects on students when resources are not available; (d) provide the capability of getting a report on changes in the students and in resources at variable time intervals; (e) provide a record of any student's history through the school; and (f) yield detailed, summarized reports on each activity, showing the student load on difficult activities in different time periods." Simulations models can be used not only to evaluate proposed organizational designs for academic institutions, but also to revise these structural schemes more easily and cost-effectively than can be done in actual schools. Five high schools from several states were selected for studying the feasibility of designing organizational structures via computer simulation. The computer model was programmed in JOVIAL, and it executed a number of runs which mimicked 1,000 students going through a regimen of one self-paced course per semester. For arbitrary reasons 200 simulated students were designated as "fast", 600 as "medium", and 200 as "slow". The model could tract a student through typical processes encountered in a semester's regimen. Following preliminary analysis and input-data description, the computer model readily recommended organizational design changes in the schools, so that they could more easily accommodate the implementation of instructional media.

Some Simulation Snares

The utilization of computer simulation techniques to study psychosocial systems are not without their pitfalls. Nunn (1973) mentioned that one of these traps is the fundamental measurement problem. As Roberts

(1964) revealed, "...intangible factors are often more difficult to model and impossible to measure either accurately or in a noncontroversial manner, but they are of vital importance to organizational behavior." Crane (1962) claimed, in a substantiating fashion, that if simulated behavioral data does not validate well against realistic behavioral data, then it is impossible to ascertain whether the fault lies with the computer model or the measures of behavior without subsequent research. Contrarily, Back (1963) stated, regarding the mathematical exactitude of some computer models, that "...the price of the precision is the decline in the relevance to actual problems...." Kaczka and Kirk (1971), however, affirmed that since psychosocial systems are extremely complicated, then specification of the functional relations among variables frequently lack the accuracy required in computer simulation studies. Nevertheless, Gregg (1965) maintained that because human operators are "...probabilistic, nonlinear, and highly variable, [they are] much more complex than any existing or conceivable machine....," only certain characteristics of human performance are simulated via computer, not the entire behavioral repertoire. Dutton and Briggs (1971) earnestly warned investigators about the "complexity dilemma", constructing computer simulation models which are more complicated than the actual systems to be imitated. Also, Bekey (1971) implied that decomposition or molecularization of complex social systems into smaller subsystems might not be readily apparent. This could preclude a computer simulation study or synthesis of these subsystems.

Marshall (1967) mentioned that, regarding computer simulation of organizational behavior, it might be difficult to formulate performance criteria. Likewise, Bekey stated that "'[c]riterion functions' may be difficult to define, optimizations may be oversimplifications, or criteria may be subjective, qualitative, and contradictory." According to Boguslaw and Davis (1969), another obstacle to the computer simulation of social systems, might be the inconsistency between the modeler's specification of "critical" variables in a realistic social situation to be simulated, and the perceptions of the individuals in that situation. Stephan (1968) asserted that the "semantic latitude" between computer programming languages and psychosocial speculative statements must be considered when attempting to simulate soft systems. Otherwise, researchers might not be aware of the possible incongruities that could exist among many precisely programmed computer models of the same obscurely stated social theory. In a parallel fashion, Crane (1962) declared that "...[a] typical criticism of computer simulation is that the computer can only reproduce what is fed into it in the first place....Another criticism is that computer simulation forces one into describing behavior in an artifical manner." Similarly, Simon (1969) stated that some individuals consider a computer model as no better than the assumptions on which it is based, and as capable as the structures and processes programmed in to it. Also, Abelson (1968) admonished against attempting "...to establish an isomorphism between ongoing group process and an ongoing computer program..., there is an obvious intuitive difficulty. Computer programs are organized sequentially under the control of

the main program or 'executive'. But one does not know where to locate executive control of the social 'organism', since social groups contain multiple centers of autonomy." Likewise, Bellman and Smith (1973) mentioned that "...the only accurate simulation of reality is reality itself. Neither a text,...,nor a simulation process is able adequately to describe a human relationship."

Rowe (1965) revealed other difficulties which must be surmounted in the computer simulation of social systems, including problems due to: computer programming, data storage, search techniques, information retrieval, and function generators. Sisson (1969) asserted that if the possible gains of computer simulation techniques are to be realized, then an adequate data base should be established and maintained. Likewise, Bekey (1971) declared:

> "Data to substantiate a large model may be absent or difficult or impossible to obtain. Cost may prohibit sufficient data collection or the data may be simply unavailable or inappropriate....Available data may be 'noisy', due to the system itself or from unrefined measurement techniques...."

Also, Dawson (1962) indicated that a liability incurred from employing computer simulation methodology is its potentially high cost. However, this expense should be evaluated relative to the cost and consequences of utilizing other experimental techniques. In many research situations, though, computer simulation methodology might be the only means of tackling an otherwise insurmountable problem.

Frijda (1967) affirmed that even though some of the simulation literature refers to a computer program as a theory, it is not a theory. "[A] program represents a theory." Apparently, there are many mechanisms intrinsic to a computer program which are extrinsic to theoretical constructs such as "lower order subroutines, particularities of the programming language, operation of the computer, serial operation of digital computers." Since many aspects of a simulation program are not attributable to theory, then methodological impediments emerge. Many of these difficulties can be ascribed to the authors of simulations, who neglect to adequately differentiate what segments of a program are theoretical or atheoretical. According to Frijda, "Serious problems of communication arise in this connection. Descriptions of programs are usually presented in a discursive manner. Processes are described in more or less informal language and in a global way. Presentation is apt to be about as vague as in purely verbal theories. There is full loss of the program clarity, and it seems that one of the main advantages of computer simulation--unambiguous theory formulation--disappears at the moment it should manifest itself."

Another procedural snare consists of estimating the match between human behavior and simulation output. Evidently, very few suitable techniques exist to handle this hindrance. In endeavoring to determine the degree of

fit between human and computer protocols, the simulation researcher is confronted with a conflicting choice. In order to more fully comprehend human behavior, he tends to simulate it as accurately as possible. However, little knowledge is gained by trying to simulate all detailed trivia and irrelevant idiosyncrasies of human behavior (Frijda, 1967). Attempting to establish the fidelity of even a simple social simulation can be an almost insurmountable problem. One criterion, which may be used to arrive at the extent of detail in a computer program, is the trade-off between amount of knowledge derived versus effort expended for an exact simulation. Researchers should also be cautioned against the effortlessness with which computer simulation languages permit them to mimic complex behavior. This has associated with it the trap of attempting to simulate with too much detail. Generally, a precise simulation has many presumptions embedded within it, and this might prolong the learning period for prospective users. Also, an intricate simulation can easily consume vast amounts of computer time (Fishman & Kiviat, 1960). As can be seen, the degree of complexity or molecularity of a computer simulation can have many untoward effects.

Obviously, human behavior, individual or social, is much more difficult to simulate than physical processes. Many individual and social simulations include representations of decision makers or information processors. According to Van Horn (1971), models of these kinds of behaviors become very rare and uncertain. Apparently, sufficient and universal paradigms of human cognitive activity have not been developed up to now. Van Horn stated: "The satisficing, limited-capability man of March and Simon (1958) appears, on the surface to differ greatly from the rational economic man. If the modeler accepts the March-Simon view, he can with great effort construct a model of a specific type of man; but an operable general model has yet to appear." Also, there are instances in simulating when parallel systems must be imitated by serial computers. Some simulation languages facilitate the description of these simultaneous systems by sequential programs. However, Clancy and Fineberg (1965) cautioned against simulating with "pseudo-parallel" programs. If a simulation scientist is to "think parallel", then he must be unincumberred from "the chore of ordering problem statements."

Naylor, Balintfy, Burdick and Chu (1966) claimed that "...the problem of verifying simulation models remains today perhaps the most elusive of all unresolved problems associated with simulation techniques." Evidently, the primary reason for neglecting to even discuss this subject matter is that the validation of computer models entails the most puzzling methodological problem associated with simulation procedures. If simulations are constructed from only theoretical relationships and artificial data without some kind of empirical verification, then these efforts are meaningless (Naylor & Finger, 1967). According to Fishman and Kiviat (1968), verification, validation, and problem analysis demand a considerable amount of attention on the part of the simulation researcher. They defined these tasks as follows: "<u>Verification</u> determines whether a model with a particular mathematical structure and data base actually behaves as an experimenter

assumes it does. Validation tests whether a simulation model reasonably approximates a real system. Problem analysis seeks to insure the proper execution of the simulation and proper handling of its results; consequently it deals with a host of matters: ...efficient allocation of computer time, proper design of tests of comparison, and correct estimates of sample sizes needed for specified levels of accuracy."

Fishman and Kiviat (1968) claimed that verifying the presumption of independence is a paramount problem in simulation experiments. The pseudo-random number generator can be checked separately from the simulation structure. This is to test whether or not in fact it produces series of independent random numbers. The structures of simulation models should themselves be verified to establish whether or not their outputs are tolerable. Consequently, unwanted or unacceptable system performance can be easily eliminated. This is especially true regarding simplistic assumptions which can unwittingly produce output differing substantially from what is expected. Also, the verification of simulation structure is useful for establishing whether simplistic paradigms can be substituted for complex ones.

Van Horn (1971) defined validation as "...the process of building an acceptable level of confidence that an inference about a simulated process is a correct or valid inference for the actual process. Seldom, if ever, will validation result in a 'proof' that the simulator is a correct or 'true' model of the real process." Rather, he viewed validation as a trade-off problem--weighing the cost of each increment in simulation fidelity versus the value of the knowledge gained regarding the imitated system. Van Horn stressed that there is "...no such thing as 'the' appropriate validation procedure. Validation is problem-dependent." If this is truly the case, then certainly trying to select the proper validation procedure is a potential pitfall for the simulation scientist.

Validation is important in computer simulation studies for several reasons. This technique easily enables the researcher to produce extremely complex or intermingled models. In many instances, structural assumptions and dynamic processes intrinsic to a computer simulation are often not even apparent to the modeler himself, let alone the potential user or causal observer. Some simulation models appear to have a certain degree of face validity to the naive. Van Horn mentioned too that, at times, computer models are designed and developed to study situations for which no empirically derived data exist. Under these circumstances, the researcher usually makes inferences concerning the object of the investigation, based upon extrapolations from an "experience base." Consequently, the simulation scientist is confronted with an important problem. He must somehow determine if "...his insight applies to a property of the actual process or merely to a pecularity of the simulation." There is no solution to this problem within the simulation itself. According to Van Horn, the researcher "must look outside" the computer model.

There are many cases of computer modelling, in which the researcher must concern himself with establishing the validity of overly simplistic simulations, in the context of very realistic events. This may facilitate to some extent the establishment of the validity of a simulation exercise. However, another paramount problem is produced--that of the "trade-off between 'validity and inference'--or,...,that between realism and formalism...." (Pfaff, 1969). A computer model which may be formally elegant and sophisticated may also be irrelevant and idealistic. Somehow, the simulation scientist must resolve this salient issue. Otherwise, on the one hand, he is just going through mental gymnastics; on the other hand, he is just manipulating the artificial. Mitroff (1969) implied that this problem "...remains as formidable and as elusive as ever. This state of affairs is due to a number of factors. For one, the concepts of 'validation' and 'simulation' depend for their elucidation on a host of underlying philosophical concepts. Unfortunately, these concepts are themselves formidable and elusive. For example, consider that 'to simulate' means to simulate some aspect of reality. Thus, for better or for worse, any discussion of the concept of simulation must sooner or later, either explicitly or implicitly, come to grips with the concept of reality. As difficult as this task is,...there is much of a practical benefit to be gained by making explicit one's concept of reality."

Naylor, Balintfy, Burdick, and Chu (1966) suggested a three-stage procedure for verifying computer models. This technique consisted of three distinct methodologies: (1) "synthetic priority" (to establish a set of postulates which describe the system under investigation), (2) "ultraempiricism" (to verify statistically the hypotheses upon which the system is grounded), and (3) "positive economics" (to determine the computer model's ability to forecast the behavior of the system of interest). This eclectic approach for model confirmation demands that each of these three techniques be followed since each of them is necessary, but not sufficient for effective simulation verification. Also, verifying or validating any sort of model connotes that the researcher has (1) defined criteria capable of distinguishing between "true" models and "untrue" models, and (2) exercised his skill to apply these standards to a model when appropriate (Naylor & Finger, 1967).

Attempting to reach an agreement upon which criteria should be used to verify a model, is another almost insurmountable simulation snare. Some process criteria of organizational effectiveness which can be used in simulation studies are "[1]<u>steady-state efficiency</u>...[which] measures efficiency when the levels of throughput and the nature of throughput...remain relatively stable over time...[2]<u>operating responsiveness</u>...[which] measures the abilities of an organization to make quick and efficient changes in the levels of throughput...[3]<u>strategic responsiveness</u>...[which] measures the firm's ability to respond to changes in the nature...of its throughput...[and,4] <u>structural responsiveness</u>...[which] measures the capabilities of an organization to change itself". According to Ansoff and Brandenburg

(1971), these four distinct dimensions of organizational behavior often produce evaluative criteria which are usually mutually conflicting or antagonistic. Therefore, to attempt to maximize one criterion may simultaneously minimize another. This is another potential pitfall of simulation methodology--related and opposed criteria. Under these conditions, the relevancy of any standard is contingent upon the specific priority or utility of objectives which the researcher has in mind at any given moment. Also, if the simulation model mimics some speculative system, then it is entirely possible that no validation can be conducted. This is so since the criteria specified may be completely hypothetical, with no real-world analogs. Consequently, if no actual numeric data exist for some speculative system, then it is highly unlikely that validation of the simulation can be completed (Fishman & Kiviat, 1968).

Over the years, the capacity to simulate complex systems has been developed to the degree where previously unwieldly problems are now manageable. However, several salient statistical issues which have accompanied advancements in simulation methodology are still very prevalent, and have not been satisfactorily solved. Some researchers are not aware that these important problems even exist (Fishman & Kiviat, 1968). According to Abelson (1968), "statistical techniques are presently underdeveloped and underapplied in simulations of social behavior. In part this has been due to preoccupation with the primary task of getting the simulations running, in part because slow computational facilities have in some cases made the cost of repeated simulations prohibitive. However, there has also been general innocence of the necessity for careful statistical treatment of simulation results and/or ignorance of what specific techniques might be applicable."

One salient statistical issue, which is intrinsic to simulation of stochastic systems, is that of autocorrelation. It is extremely erroneous to presume that data produced within a computer model are independent. In fact, typical techniques of generating random numbers within simulation experiments create undesirable correlation among the data. This can produce misjudgments such as underestimating the statistical reliability of response measurements, or overestimating sample means and variances. That is, "this error is caused by failure to account for autocorrelation in system response time-series generated by a simulation model (Fishman & Kiviat, 1968)." Because of these autocorrelated stochastic processes, data generated by computer models in the form of time series or sample records are not amenable to analysis by conventional statistical techniques, which assume independent measures. A typical procedure followed to minimize this autocorrelation is to linearly transform the time-series data. Then, traditional statistical techniques are used to analyze the transformed data. However, this method discards a considerable amount of important information about a simulated system (Fishman, 1967; Fishman & Kiviat, 1967a, 1967b, 1968; Naylor, Burdick, & Sasser, 1969).

There are at least two other simulation snares which are somewhat related to the above issues. A pervasive problem has to do with the question,

"Have enough trials been processed by the simulator?" (Kabak, 1968). Usually, in computer modelling studies, a simulation exercise is stopped when the variance of some statistic is within certain limits. Yet, because of the autocorrelation which exists between adjacent trials, the variance cannot be readily computed. Establishing the reliability of parameter estimates, is another paramount problem in Monte Carlo experiments. Even if one were to make the erroneous presumption of independently and identically distributed stochastic variables, sampling would be prohibitively expensive. This is so since "a 10-fold improvement in reliability require[s] a 100-fold increase in sample size (Fishman & Kiviat, 1968)." A critical statistical problem involves developing procedures for reducing the estimated variance for certain sample sizes.

Other simulation pitfalls concern choosing--the length of a computer modelling experiment, the sampling interval, and the technique to handle important timing problems. According to Fishman and Kiviat (1968), one of the most irksome computer modelling topics involves the length of time to run a simulation study. Evidently, enough information is rarely available beforehand to determine how long to run the modelling exercise. To run the simulation for a "sufficiently long" time is to indeterminant, to say the least, for establishing an objective policy regarding the cessation of these studies. It seems that researchers have implicitly presumed that the effects of a simulation's starting conditions would be completely eliminated, if the model were permitted to run for a "sufficiently long" time. Yet, Fishman (1967) affirmed that "...it is often difficult to determine what minimum length of time suffices for meaningful analysis." Selecting the proper sampling interval is another problem inherent to simulation investigations. Typically, time is advanced by "unit-by-unit and event-to-event" techniques. There are instances when computations are simplified by employing within the simulation time-advance procedures. This is due to an absence of an event list and its associated processing. However, seldom are there periods during which a lack of events prevails; consequently, time-advance procedures are inefficient (Emshoff & Sisson, 1970). Major timing problems in simulation studies, which seem to defy any sophisticated solutions, involve modelling "asynchronous processes" and coordinating "simultaneous events." Apparently, attempting to implement the programming requirements for asynchronous events is extremely difficult to exercise efficiently. In fact, it may not even be worth the tremendous effort. A related issue deals with endeavors to somehow coordinate simultaneous events. Since digital computers are sequential processors, it is almost impossible to attempt to mimic simultaneous occurrences (Kiviat, 1967).

There are still more difficulties which can be encountered in computer modelling experiments. If a complete factorial design is utilized for the investigation, then an almost unwieldy number of data points must be generated by the simulation. This could easily involve very excessive amounts of computer time (Hunter & Naylor, 1969). Obviously, data produced

by a computer modelling experiment are costly. However, this expense can be minimized, if the expenditure for further observations is weighted against the expected increment in information derived from such data (Naylor, Burdick, & Sasser, 1969). Some of the most troublesome methodological problems in simulation consist of starting the model and obtaining measurements which are independent of the model's initial and terminal conditions. In order to overcome the distortion or artificiality produced by the model due to its initial starting conditions, the simulation is usually permitted to warm-up for some time. Then, "...(a) exclude data from some initial period from consideration, and (b) choose starting conditions that make the necessary excluded interval as short as possible (Conway, 1963)." Koopman and Berger (1967) mentioned that a limitation of simulation studies consists of seldom having sufficient funds and time to conduct thoroughly a sensitivity analysis. Consequently, it would be tedious to determine the sensitivity of the simulation results to changes in the parameters. Also, because of the impracticality or impossibility of having access to an entire population of data, researchers must consider samples from that population.

A problem arises in computer modelling concerning selection of sampling distributions. Which one is appropriate? Which one do you use? That is, how do you adequately describe the input data for a simulation model? Should the researcher use some form of discrete distribution (Bernoulli, Binominal, Hypergeometric, or Poisson) or continuous distribution (Normal, Chi-Square, Rectangular, or Exponential) (Mize & Cox, 1968)? Obviously, failure to select the appropriate sampling distribution(s) for a simulation exercise can have numerous detrimental effects. Similarly, the distributions of output variables from simulation exercises are also important since the researcher must deal with these distributions when statistically analyzing the results of the simulation runs. Endeavoring to describe the forms of the distributions of these output data is difficult too. This is primarily attributed to the fact that these "...distributions are not given explicitly but are determined by a complex interaction between a large number of completely deterministic tasks and a relatively small number of tasks with probabilistic elements which are produced with random number generators. It is very difficult to discern what might be the form of the probability laws of the output variables by inspection of the total system of mathematical specifications for the simulation program (Dear, 1961)."

CONCLUSIONS

From the foregoing, it is apparent that many computer simulation studies not only of distinct scopes (micro or macro), but also of disparate natures (theoretical or operational), have been conducted and reported. These investigations have undoubtedly demonstrated the feasibility of employing computer simulation methodology to analyze and synthetize the behavior of both psychosocial and sociotechnical systems. Obviously, a great gamut of psychosocial parameters and variables were indubitably and intrinsically incorporated and manipulated in the published computer-modelling experiments.

The surveyed studies exhibited that simulation techniques have tremendous utility for investigating diverse organizational and social systems. This reported research corroborated the following asserted advantages and claimed capabilities derived from employing computer simulation methodology, namely:

(1) to control, manipulate, and measure the intermingled interrelationships or interactions among the many parameters and variables in psychosocial and sociotechnical systems;

(2) to wield the confounded and complex structures intrinsic to social and organizational entities due to their systemic natures;

(3) to indicate, imitate, and activate the dynamics and processes essential to temporal social systems;

(4) to expand typical psychosocial, experimental techniques to test theoretical extrapolations or implications regarding organizational systems;

(5) to express and produce psychosocial theories and hypotheses by employing computer programming languages, structures, and symbologies;

(6) to control experimentally confounding factors due to extrinsic variables, reactive measures, and expectancy effects which plague psychosocial research;

(7) to design, develop, and evaluate organizational structures and processes without cumbersome and costly, real-world trial and error; and

(8) to imitate, implement, and choose optimal organizational changes without interferring or interrupting the actual system itself.

In this writer's opinion, the accrued advantages and potential payoffs resulting from the use of computer simulation to study psychosocial and sociotechnical systems far outweigh the asserted snares and pronounced pitfalls encountered in its implementation.

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